DRAFT

RECOVERY PLAN FOR ISLAND FOXES (*Urocyon littoralis*) ON THE NORTHERN CHANNEL ISLANDS

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Executive Summary

Current Species Status: The island fox (*Urocyon littoralis*), a diminutive relative of the mainland gray fox (*Urocyon cinereoargenteus*), is distributed as six subspecies, one on each of the six largest California Channel Islands. Three of the subspecies occur on the northern Channel Islands, within the boundaries of Channel Islands National Park: the San Miguel island fox (*U. l. littoralis*), the Santa Rosa Island fox (*U. l. santarosae*), and the Santa Cruz island fox (*U. l. santacruzae*). The latter occurs both on NPS lands and those owned by The Nature Conservancy on Santa Cruz Island.

On the southern Channel Islands, the San Nicolas island fox (*U. l. dickeyi*) and San Clemente island fox (*U. l. clementae*) occur on lands managed by the U. S. Navy, and the Santa Catalina island fox (*U. l. catalinae*) occurs on lands managed by the Santa Catalina Island Conservancy.

The species was formerly a category II candidate for federal listing, but is not currently listed by U.S. Fish and Wildlife as threatened or endangered under the Federal Endangered Species Act. In 2000 the U.S. Fish and Wildlife Service was petitioned by the Center for Biodiversity to list four of the six island fox subspecies as endangered. The species is listed by the state of California as a threatened species.

Four of the six island fox subspecies have declined by as much as 95% since 1994, including the three subspecies that occur in Channel Islands National Park. Two island fox subspecies are at critically low population sizes (San Miguel island fox at 17 individuals, and Santa Rosa island fox at less than 30). Santa Cruz island foxes may number less than 100, and Santa Catalina island foxes declined by 90% in under a year. The population on San Clemente is also in decline. The San Nicolas island fox population appears to be stable and dense. Total number for the species is approximately 1,300 adults, which is less than 25% of what it may have been in 1993-1994. Recent annual survivorship in the wild is about 10% on San Miguel Island.

The primary threats to island foxes are predation by golden eagles (*Aquila chrysaetos*) on the northern Channel Islands, canine distemper virus on Santa Catalina Island, collision with vehicles on San Clemente and San Nicolas Islands, and low population sizes on San Miguel and Santa Rosa Islands. Potential threats include the introduction and spread of canine diseases.

Habitat Requirements and Limiting Factors: Island foxes are omnivorous and occupy all habitat types on the Channel Islands, but prefer to forage in native vegetation, as opposed to alien annual grasslands. Seasonal abundance of invertebrates may be important, and deer mice (*Peromyscus maniculatus*) may be important food items during the period of weaning and pup growth. Shrubby or woodland habitat provides more cover from aerial predators than do more open habitat types, such as alien annual grasslands. The current level of golden eagle predation is considered unnatural, for two reasons. First, a large population of feral pigs allows golden eagles to winter and breed on Santa Cruz Island. Second, an historic golden eagle deterrent, the bald eagle (*Haliaeetus leucocephalus*), has been missing from the northern Channel Islands since the mid 20th century due to persecution and the impacts of organochlorine pesticides.

Absent significant unnatural predation and introduced canine diseases, island fox populations are limited most by territory availability. Island foxes generally mate for life and are mostly monogamous, with mated pairs occupying discrete territories. Reproductive success is generally low for the species, and may limit the ability of island fox populations to recover following catastrophic decline.

Recovery Goals and Objectives: The goal of this plan is to minimize the threat of extinction for the three island fox subspecies occurring in Channel Islands National Park, thus recovering those subspecies to population levels and

vital rates which are self-sustaining, or at least require a minimum of management action to maintain. To attain this goal, the following objectives need to be achieved:

- Remove or minimize mortality factors for all populations, focusing primarily on the human-caused mortality factors of golden eagle predation and canine disease
- Augment wild populations of those subspecies with critically low populations, via captive breeding
- Establish management and monitoring programs to protect wild fox populations
- Restore natural ecosystem elements and processes to the northern Channel Islands

Recovery Criteria: Each subspecies will be considered recovered when it is stable and/or increasing, at a population level that reduces the risk of extinction from demographic stochasticity to less than 5% over a 50-year period. Demographic modeling has been used to develop appropriate population criteria. Accordingly, a subspecies will be considered recovered when it has met the recovery criteria for target population size and target vital rates given in Table 3 of this plan (p. 24). Annual population monitoring will return annual vital rate estimates which can be compared to the recovery criteria.

Conservation Measures Taken: Based upon recommendations from an ad hoc working group, the NPS began initiating emergency actions in 1999, with the objectives being to remove the primary mortality factor currently affecting island foxes (golden eagle predation), and to recover island fox populations to viable levels via captive breeding. Eagle relocation commenced in summer 1999. Between November, 1999, and March, 2001, 14 eagles were removed from the Santa Cruz Island and relocated to northeastern California. There are currently at least seven golden eagles on Santa Cruz Island.

In 1999 the NPS established an island fox captive breeding facility on San Miguel Island, and added a captive breeding facility on Santa Rosa in 2000. Fourteen foxes were brought into captivity on San Miguel and only one is known to exist in the wild. One litter of two pups was produced in 2000 on San Miguel. Three litters were born on Santa Rosa in spring 2000, to females that had conceived in the wild. There are currently 22 foxes in captivity on Santa Rosa, and less than five are thought to remain in the wild.

Actions Needed:

1. Complete initial removal of golden eagles from northern Channel Islands.
2. Implement monitoring/response program for future golden eagles.
3. Establish and maintain captive breeding facilities on San Miguel and Santa Rosa Islands.
4. Supplement wild populations with captive-reared foxes.
5. Evaluate the need for captive breeding on Santa Cruz Island.
6. Develop adaptive management program that ties future management actions to pre-established monitoring criteria.
7. Implement annual population monitoring of each subspecies/population.
8. Enforce no-dog policy on islands, and vaccinate working dogs.
9. Educate the public about potential disease transmission from domestic dogs.
10. Remove feral pigs from Santa Cruz Island.
11. Restore bald eagles to the northern Channel Islands.

Total Estimated Cost of Recovery: Total costs of recovery actions are estimated at $5,806,000, plus costs that are not yet determined. Total cost of unfunded needs for which the National Park Service will seek funding is $4,926,000.

Date of Recovery: Recovery of island fox subspecies could occur as soon as 2011, if recovery criteria are met for all populations.

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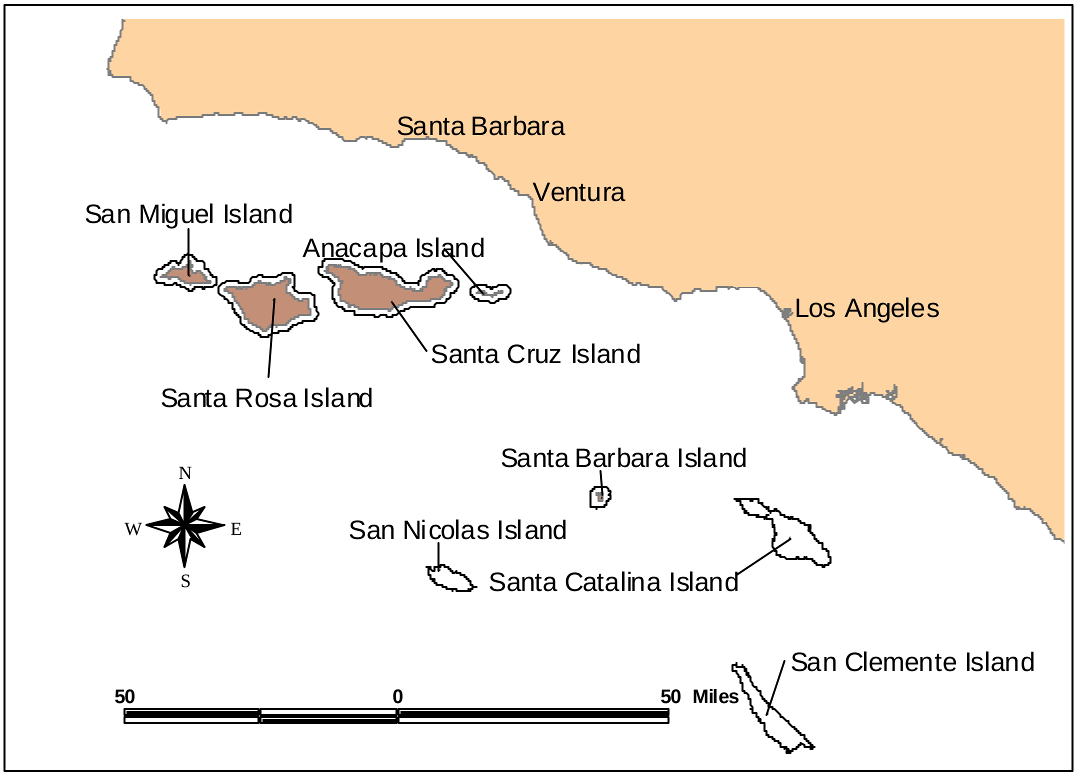

Figure 1. Island foxes (*Urocyon littoralis*) inhabit the six largest of California's eight Channel Islands. Channel Islands National Park (shown in solid) comprises the five northernmost islands. The park boundary (black line) extends one nautical mile from the shoreline. Subspecies on the northern Channel Islands include the San Miguel island fox (*U. l. littoralis*), the Santa Rosa Island fox (*U. l. santarosae*), and the Santa Cruz island fox (*U. l. santacruzae*). Subspecies on the southern Channel Islands include the San Nicolas island fox (*U. l. dickeyi*), the Santa Catalina Island fox (*U. l. catalinae*), and the San Clemente Island fox (*U. l. clementae*).

Part I Introduction

Background

The island fox (*Urocyon littoralis*), a diminutive relative of the gray fox (*U. cinereoargenteus*), is endemic to the California Channel Islands. It is distributed as six subspecies, one on each of the six Channel Islands on which the fox occurs. Both morphologic and genetic distinctions support the classification of separate subspecies for each island (Collins et al. 1993, Gilbert et al. 1990, Goldstein et al. 1991, Wayne et al. 1991).

Four of six island fox subspecies have recently experienced catastrophic declines. Fox populations on the northern Channel Islands have declined by as much as 95% from 1993-1994 levels, likely due to mortality by golden eagles (*Aquila chrysaetos*) (Roemer 1999). The island fox population on Santa Catalina Island declined precipitously in 1999-2000, likely due to an epidemic of canine distemper (Timm et al. 2000). Demographic modeling suggests that the population on San Clemente Island is also in decline (Roemer et al. 2000b).

The island fox population on San Miguel Island declined sharply in the last five years (Coonan et al. 1998, Coonan et al. 2000) with the adult population falling from 450 in 1994 to 15 in 1999. Island foxes on Santa Cruz Island have declined from approximately 1,300 adults in 1993 to approximately 130 in 2000 (Roemer 1999, G. Roemer, University of California, Los Angeles, unpubl. data). Foxes on Santa Rosa Island may have numbered approximately 1,500 in 1994 (Roemer et al. 1994) but now number less than 30 (T. Coonan, unpublished data).

In a study of island foxes on Santa Cruz Island in 1993-1995, golden eagle predation was identified as cause of death for 19 of 21 island fox carcasses (Roemer 1999). A radiotelemetry study on San Miguel Island in 1998-1999 confirmed that golden eagle predation was a major mortality source on that island as well (Coonan et al., in prep.) This level of golden eagle predation is unnatural. Until the late 1990's, golden eagles never bred on the Channel Islands; their recent appearance is likely due to a prey base, feral pigs (*Sus scrofa*) that was not present prehistorically (Roemer et al., in review). The absence of bald eagles (*Haliaeetus leucocephalus*), which bred historically on the islands and whose presence may have kept golden eagles away, is another factor possibly driving increased golden eagle predation. Moreover, on much of the northern Channel Islands, historic sheep grazing changed the predominant vegetation from shrub to non-native grasslands, which offer much less cover from aerial predators.

Based on an analysis of extinction likelihood, Roemer (1999) concluded that, if mortality and reproduction continued at rates seen just prior to intervention, both the San Miguel and Santa Cruz subspecies would decline to extinction within a matter of several years.

Concerned about the potential loss of three subspecies of island foxes from its lands, the Park convened an island fox working group in April, 1999 to consider the available information and develop strategies to recover island fox populations to viable levels. The group (see Appendix A) concluded that:

- predation by golden eagles is the primary mortality factor now acting on the populations
- disease or parasites may be compounding the effects of predation
- natural recruitment is low; and that the most effective conservation measure that could be taken right now is to increase survival of pups, juveniles and adults by reducing or eliminating golden eagle predation

At the same time, the group recognized that the size of the fox populations on these three islands is critically small; the natural reproductive potential is low; our knowledge of all of the factors contributing to the population decline may be incomplete; and the effectiveness of proposed golden eagle management efforts in reducing or eliminating predation is yet to be seen. Therefore, the group concluded that establishment of a fox sanctuary and captive breeding program was necessary to safeguard individual foxes and to augment natural recruitment into the population.

Current and Previous Conservation Efforts

Channel Islands National Park began initiating emergency actions in 1999, with the objectives being to remove the primary mortality factor now affecting island foxes (golden eagle predation), and to recover island fox populations to viable levels via captive breeding. Eagle relocation commenced in summer 1999, when raptor biologists from the Santa Cruz Predatory Bird Research Group, working under a cooperative agreement with the Park, began removing golden eagles from the northern islands by trapping the birds and releasing them in northern California. Between November, 1999, and March, 20001, 13 eagles had been removed from the island. Several of these were members of pairs that had begun defending territories but had not nested. Satellite telemetry shows that none of the relocated eagles have attempted to return to the islands, or even to cross the Sierra Nevada. At least seven eagles remain on the island and removal efforts will continue in spring 2001, but the island will continue to attract golden eagles until feral pigs are removed.

In 1999 the NPS established an island fox captive breeding facility on San Miguel Island, and added a captive breeding facility on Santa Rosa in 2000 (Coonan and Rutz 2001). The program is being conducted under the guidance of a captive breeding sub-group of the island fox working group. Fourteen foxes were brought into captivity on San Miguel and only one is known to exist in the wild. Of those 14, only four were males, and they were paired with females for the 1999-2000 breeding season. Only one of those pairs produced a litter (of two pups). Three litters were born on Santa Rosa in spring 2000, to females that had conceived in the wild. There are currently 22 foxes in captivity on Santa Rosa.

The ad hoc island fox working group met again in summer, 2000, to evaluate the success of the emergency measures implemented thus far, and to begin development of a long-term recovery plan for the species. The group recommended that the measures taken thus far on the northern Channel Islands (golden eagle removal and captive breeding) be continued and form the basis for long-term recovery for those subspecies. All golden eagles need to be removed from the northern Channel Islands, and capability needs to be developed for future eagle monitoring and quick response by a removal team. Initial captive breeding efforts need to be expanded into a professional, long-term captive breeding program geared toward a level of production that will result in sufficiently large, self-sustaining wild populations of island foxes. Identification of recovery goals for each population/island should be aided by demographic modeling, which would give estimates of vital rates (population size, survivorship, and reproductive success) required to ensure persistence of fox populations over time. A year-long radiotelemetry study on Santa Cruz Island would help refine estimates of demographic parameters, and would determine whether eagle removal has resulted in increased survivorship.

The group recognized the threat of canine diseases as a potential catastrophic threat to all island fox populations, underscored by the recent dramatic island fox decline on Santa Catalina Island attributed to canine distemper virus. Current effects of canine distemper virus on Catalina need to be mitigated, and domestic dog use on all islands needs to be strictly managed. Public education efforts need to be focused on this issue, in order to emphasize the dangers posed to island foxes by visitors bringing domestic dogs to islands.

Like the domestic dog issue, the need for efficient, standardized monitoring is common to all six populations. The group recognized the need to standardize population monitoring across all islands.

Although the group recognized the need for a species-wide recovery plan, there is currently no formal vehicle to accomplish such a planning effort. The species is not listed, and so U.S. Fish and Wildlife Service will not prepare a formal recovery plan for the species. A species-wide plan would require approval by the four landowners responsible for island fox management on their lands: the National Park Service, The Nature Conservancy, the U.S. Navy, and the Santa Catalina Island Conservancy. Given the complex ownership and different missions of the landowners, development of such a plan outside the framework of an official recovery program may take considerable time. Nonetheless, the NPS will take the lead in developing a species-wide plan, and will contact other landowners about involvement. If the species is federally listed, such a plan can form the foundation for an official recovery plan for the species. This recovery plan for island foxes on the northern Channel Islands would be part of a species-wide plan.

Conservation efforts are currently under way for island fox populations on non-Park islands. On Santa Catalina Island, The Santa Catalina Island Conservancy, working in conjunction with the Institute for Wildlife Studies, has taken a series of measures to mitigate the effects of canine distemper virus on that island's fox population. Following successful trials of a recombinant vaccine for distemper on captive Catalina island foxes, the Institute began vaccinating foxes in the field (Timm et al. 2000). To date almost 150 foxes from the area west of Twin Harbors have been administered the vaccine, which requires two vaccinations over a period of several weeks. In order to recolonize the area east of Twin Harbors, the Institute has released six juvenile foxes from the west end into that area. The Conservancy and the Institute have also begun a captive breeding program to aid in recolonizing the eastern part of the island. As of February, 2001, several large captive breeding pens had been built, and the Institute was planning on bringing nine pairs of island foxes into the facility.

The U.S. Navy has implemented conservation measures and conducted basic island fox monitoring on both San Nicolas and San Clemente Island. To mitigate the impact of vehicles as a mortality source, speed limits have been established and education programs have been developed targeting island personnel. Garbage containers have been fox-proofed, and hand-feeding of foxes has been discouraged.

Biological Information

Description and Taxonomy

A diminutive relative of the mainland gray fox (*Urocyon cinereoargenteus*), the island fox weighs approximately 3 to 6 pounds and stands approximately one foot tall. The island fox is distinguished from the gray fox by its darker pelage and its smaller size (Collins 1982); most linear measurements of island foxes are 25% smaller than those of the gray fox. Dorsal coloration is grayish-white and black, and the base of the ears and sides of the neck and limbs are cinnamon-rufous in color (Moore and Collins 1995). The underbelly is a dull white, and the tail is conspicuously short. Island foxes display sexual size dimorphism, with males being larger and heavier than females (Collins 1982, 1993).

The island fox was first described as *Vulpes littoralis* by Baird in 1857 from the type locality on San Miguel Island, Santa Barbara County, California (Baird 1857). Merriam (1888, in Hall and Kelson 1959) reclassified the island fox into the genus *Urocyon* and later described island foxes from Santa Catalina, San Clemente and Santa Cruz island as three separate species (*U. catalinae*, *U. clementae*, and *U. littoralis santacruzae*)(Merriam 1903). Grinnell et al. (1937) revised Merriam's classification, placing foxes from all islands under the species *U. littoralis* and assigning each island population a subspecific designation (*U. l. catalinae* on Santa Catalina Island, *U. l. clementae* on Clemente Island, *U. l. dickeyi* on San Nicolas Island, *U. l. littoralis* on San Miguel Island, *U. l. santacruzae* on Santa Cruz Island, and *U. l. santarosae* on Santa Rosa Island). Recent morphological and genetic studies support this division of the *U. littoralis* complex into six subspecies, each restricted in range to a single island (Collins 1991a, 1993, Gilbert et al. 1990, Goldstein et al. 1999, Wayne et al. 1991).

Legal Status

Due to its limited geographic distribution and small population size on several islands, the island fox has been listed as threatened by the state of California (California Department of Fish and Game 1987). The species was formerly a category II candidate for federal listing as endangered or threatened.

Distribution, Evolution and Genetics

Island foxes inhabit the six largest islands (San Miguel, Santa Rosa, Santa Cruz, San Nicolas, Santa Catalina, and San Clemente islands) off the coast of southern California (Fig. 1). Genetic evidence suggests that all island foxes are descended from one colonization event (George and Wayne 1991), possibly from chance overwater dispersal by rafting on floating debris (Moore and Collins 1995). Fossil evidence indicates that island foxes have been on the northern Channel Islands (San Miguel, Santa Rosa, and Santa Cruz) for over 10,000 to 16,000 years (Orr 1968). Island foxes are thought to have existed on the northern Channel Islands during a period when Santa Cruz, Santa Rosa and San Miguel were one land mass referred to as “Santarosae”, last known to have been united 18,000 years before present (Johnson 1978, 1983). Island foxes may have reached the southern Channel Islands (San Nicolas, San Clemente, and Santa Catalina) much more recently (2,200 to 3,800 years ago), and were most likely introduced to these islands by Native Americans as pets or semi-domesticates (Collins 1991a,b). However, island fox remains recently recovered from San Nicolas Island extend this time period to approximately 5,200 years before present (Vellanoweth 1998).

Morphologically, the species exhibits inter-island variability in size, nasal shape and projection, and the number of tail vertebrae (Collins 1982). Genetic evidence supports the separation of the species into six distinct subspecies, and confirms the pattern of dispersal suggested by archeology and geology. A study of genetic variability in DNA restriction fragments in island foxes (Gilbert et al. 1990) revealed that inter-island variability was greater than intra-island variability. Phylogeny based upon restriction fragment variability supports the geological evidence for the sequence of isolation for each island, and each population, as rising sea levels separated Santarosae into the northern Channel Islands. Santa Cruz separated from the other northern islands first, about 11,500 years ago, followed by the separation of San Miguel and Santa Rosa about 9,500 years ago. Together with the fossil record, restriction fragment evidence indicates that San Clemente was the first southern Channel Island colonized, probably by immigrants from San Miguel. Dispersal then occurred from San Clemente to San Nicolas and Santa Catalina.

Island forms generally have less genetic variability than their mainland counterparts, and island foxes are no exception. Mainland gray foxes were found to be more variable in morphology, allozymes, mitochondrial DNA, and at hypervariable nuclear DNA than island foxes (Goldstein et al. 1999, Wayne et al. 1991a). The smallest island fox populations, San Miguel and San Nicolas, showed the least genetic variability, and the San Nicolas population was actually monomorphic in allozyme, hypervariable minisatellite and microsatellite DNA, and mitochondrial DNA, which is highly unusual among mammals. This lack of variability could be attributed either to extensive inbreeding, or bottlenecking resulting from low population densities (George and Wayne 1991). On San Miguel and San Nicolas, the species has apparently existed for thousands of years at low population sizes, and low effective population sizes (150-1000), with low genetic variability (Wayne et al. 1991a, 1991b). The Santa Rosa and San Miguel populations were shown to be closely related.

Habitat Use and Food Habits

The island fox is a habitat generalist, occurring in all natural habitats on the islands, although it prefers areas of diverse topography and vegetation (von Bloeker 1967, Laughrin 1977, Moore and Collins 1995). Island foxes occur in valley and foothill grasslands, southern coastal dune, coastal bluff, coastal sage scrub, maritime cactus scrub, island chaparral, southern coastal oak woodland, southern riparian woodland, Bishop and Torrey pine forests, and coastal marsh habitat types. Crooks and Van Vuren (1996) found island foxes to prefer fennel grasslands and to avoid ravines and scrub oak patches on Santa Cruz Island.

Island foxes are opportunistic omnivores, taking a wide variety of seasonally available plants and animals (Collins 1980, Collins and Laughrin 1979, Crooks and Van Vuren 1995, Kovach and Dow 1981, Laughrin 1973, 1977, Moore and Collins 1995). Island foxes forage opportunistically on any food items encountered within their home range. Selection of food items is determined largely by availability, which varies by habitat and island, as well as seasonally and annually. Island foxes feed on a wide variety of insect prey, when seasonally available (Moore and Collins 1995). At certain times of the year foxes feed heavily on orthopterans (Crooks and VanVuren 1995; Moore and Collins 1995). Jerusalem crickets (*Stenopelmatus fuscus*) are important in the fox diet, and fox weights on Santa Cruz Island have been correlated with abundance of Jerusalem crickets (G. Roemer, University of California, Los Angeles, unpubl. data).

Island foxes prey on native deer mice (*Peromyscus maniculatus*), as well as introduced house mice (*Mus musculus*) and rats (*Rattus rattus*). Deer mice may be especially important prey during the breeding season, because they are large, energy-rich food items that adult foxes can bring back to their growing pups (Garcelon et al. 1999). In addition to small mammals, island foxes feed on ground-nesting birds such as horned larks (*Eremophila alpestris*) and western meadowlarks (*Sturnella neglecta*). Less common in the diet are amphibians, reptiles, and carrion of marine mammals (Collins and Laughrin 1979). Island foxes feed on a wide variety of native plants, including the fruits of *Arctostaphylos*, *Comarostaphylis*, *Heteromeles*, *Opuntia*, *Prunus*, *Rhus*, *Rosa*, *Solanum* and *Vaccinium* (Moore and Collins 1995). Arborescent fruiting shrubs do not occur on San Miguel Island, where foxes rely more on the fruits of sea-fig, *Carpobrotus chilensis*. A comprehensive treatment of island fox diet is found in Moore and Collins (1995).

The island fox is a docile canid, exhibiting little fear of humans in many instances. Although primarily nocturnal, the island fox is more diurnal than the mainland gray fox (Collins and Laughrin 1979, Crooks and Van Vuren 1995, Fausett 1993). This is thought to be a result of historical absence of large predators and freedom from human harassment on the islands (Laughrin 1977).

Social Organization and Reproduction

Island foxes generally have smaller territories, exist at higher densities, and have shorter dispersal distances than mainland fox species, such characteristics being typical of rodent populations on islands, and now recently demonstrated for island foxes (Roemer 1999, Roemer et al. in press).

In island foxes, territory/home range size and configuration are dependent on landscape features, resource distribution, fox population density, habitat type, season and sex of the animal (Fausett 1982, Laughrin 1977, Crooks and Van Vuren 1996, Thompson et al. 1998). Recorded home range estimates range from 0.24 km^2 in mixed habitat (Crooks and Van Vuren 1996) and 0.87 km^2 in grassland habitat (Roemer 1999) on Santa Cruz, to 0.77 km^2 in canyons on San Clemente (Thompson et al. 1998).

Recent results from a study on Santa Cruz Island indicate that island foxes are distributed as socially monogamous pairs occupying discrete territories (Roemer et al., in press). Island fox territory size on Santa Cruz Island varied from 0.15 to 0.87 km^2 and averaged 0.55 km^2 during a period of moderate to high fox density (7 foxes/ km^2). Territory configuration changed after the death and replacement of paired male foxes, but not after the death and replacement of paired females or juveniles, indicating those adult males are involved in territory formation and maintenance. Despite being socially monogamous and territorial, island foxes are not strictly monogamous. Four of 16 offspring whose parents were identified by paternity analysis were a result of extra-pair fertilizations. All extra-pair fertilizations occurred between foxes from adjoining territories, and perhaps were facilitated by dense population and small territories.

Courtship activities occur from late January to early March (Moore and Collins 1995). In the island fox captive breeding facility on San Miguel in spring, 2000, copulations were observed during the first two weeks of March, and copulation for the one successful pair likely occurred between February 27 and March 1 (Coonan and Rutz 2001). Young are born from mid April through May after a gestation period of approximately 50-53 days. Births occurred in the island fox captive breeding facilities from April 10 to April 26, 2000. Island foxes give birth to their young in simple dens, which are usually not excavated by the foxes themselves (Laughrin 1973). Litter size ranges from one to five (Moore and Collins 1995); mean litter size for 24 dens on Santa Cruz Island was 2.17 (Laughrin 1977). The four litters produced in captivity in 2000 numbered four, four, two and one pup respectively. Island foxes exhibit biparental care, based on the capture of adult male foxes in the same traps as pups, the presence of prey outside traps containing trapped pups, and observations of adults and known offspring foraging together (Garcelon et al. 1999, Roemer 1999). By two months of age, young spend most of the day outside the den and will remain with their parents throughout the summer. Some pups disperse away from their natal territories by winter, although others may stay on their natal territories into there second year.

Although island foxes can breed at the end of their first year (Laughrin 1977), most breeding involves older animals. Coonan et al. (2000) found that only 16% of juvenile females bred over a five-year period on San Miguel Island, in contrast to 60% of older females, and Roemer (1999) found juvenile females to have lower fertility than older females on Santa Cruz Island. Adult island foxes are reported to live an average of four to six years (Moore and Collins 1995), although this may be an underestimate; Coonan et al. (1998) recorded eight individuals on San Miguel that lived 7–10 years in the wild.

Mortality Sources and Population Dynamics

With the exception of the recently discovered catastrophic mortality sources of golden eagle predation (Roemer 1999, Roemer et al. in review) and distemper outbreak (Timm et al. 2000), mortality factors for island foxes are not well known. Presumed mortality sources include disease, parasites, predation, and accidents (Moore and Collins 1995). Collision with motor vehicles is an important mortality factor on San Nicolas and San Clemente Islands (Moore and Collins 1995). On San Nicolas Island, 20 to 40 foxes are killed by vehicles annually (G. Smith, U. S. Navy, pers. comm.). Except for golden eagles, the only other reported predators of island foxes are red-tailed hawks (*Buteo jamaicensis*), which prey only on island fox pups (Laughrin 1980, Moore and Collins 1995). Island foxes have shown previous exposure to canine diseases such as canine parvovirus (Garcelon et al. 1992), but disease was not confirmed as a mortality factor until the outbreak of canine distemper virus on Catalina Island in 1999-2000 (Timm et al. 2000). To date, parasites have not been confirmed as a mortality source, although novel parasites found in the San Miguel population may affect individual health (L. Munson, University of California, Davis, pers. comm.).

Even in the absence of catastrophic mortality sources, island fox populations may have fluctuated markedly over time, but for unknown reasons (Laughrin 1980). Santa Cruz Island residents had occasionally noted periods of fox scarcity and fox abundance on that island. Low population levels on Santa Catalina Island led the state of California to list the island fox as rare in 1971. Island foxes were still considered to be at low density on Catalina in 1977 (Laughrin 1980), but by 1994 adult population size on Santa Catalina was estimated at over 1,300 individuals (Roemer et al. 1994). The population on San Nicolas was considered to be at very low densities in the early 1970's (Laughrin 1980) but may have reached 500 or so by 1984 (Kovach and Dow 1985, as cited by Wayne et al. 1991b). In 2000 the island fox population on San Nicolas was estimated as 734 foxes based on recent density estimates from three grids, and comprised mostly adults (G. Roemer, University of California, Los Angeles, unpubl. data).

Although one might expect island fox populations to fluctuate according to climate shifts, such effects have not been documented thus far. Population densities on San Miguel were high (7-15 foxes/km^3) in 1993-1994 (Coonan et al. 2000), but this was after a six-year drought had ended. The only long-term monitoring database that encompasses both drought and non-drought periods is from San Clemente Island. The island fox population has undergone a gradual decline since 1993 (Roemer 1999) but it is unclear whether climate is a factor. As apex predator in the islands' ecosystem, isalnd foxes are likely affected by climate, through its effects on the fox prey base (G. Roemer, University of California, Los Angeles, pers. comm.).

Analytical sensitivity analysis revealed that survival of pup and adult foxes, and adult fertility were the life-stage parameters that had the greatest influence on island fox population growth rate (Roemer 1999).

Current Status and Trend

Four of the six island fox subspecies have experienced precipitous declines in the last four years: San Miguel Island fox, Santa Rosa Island fox, Santa Cruz Island fox, and Santa Catalina Island fox (Coonan et al. 1998, 2000, and in prep.; Roemer 1999, Roemer et al. in review, Timm et al. 2000). Total island fox numbers have fallen from approximately 6,000 individuals (Roemer et al. 1994) to less than 2,000. Island fox populations on San Miguel and Santa Cruz islands have declined by an estimated 90-95 percent and, prior to removal of foxes from the wild for captive breeding, had a 50 percent chance of extinction over the next 5 to 10 years (Roemer 1999, Roemer et al. in review). Long-term island fox population monitoring has not been undertaken on Santa Rosa Island; however, anecdotal observations and limited trapping efforts strongly suggest that a similar decline has occurred for this subspecies as well (T. Coonan, National Park Service, pers. obs.; G. Roemer, University of California, Los Angeles, pers. comm.). Island fox populations on the northern Channel Islands are considered to be critically endangered and in need of immediate conservation action (Coonan et al. 1998, Roemer 1999). On Santa Catalina, island foxes are now rare on the larger eastern portion of the island. This decline is the result of a canine distemper outbreak that swept through the population in 1999 (Timm et al. 2000). The San Clemente population is thought to be in gradual decline for reasons that are not yet clear (Garcelon 1999, Roemer 1999). The San Nicolas island fox population appears to be at high density (5.7 to 16.4 foxes/km^2) (G. Roemer, University of California, Los Angeles, pers. comm). The small population size (Roemer et al. 1994), insular nature, lack of resistance to canine distemper and other diseases (Garcelon et al. 1992) and low genetic variability (Wayne et al. 1991) increase the vulnerability of these two subspecies (Roemer 1999).

San Miguel Island

The first quantitative surveys for island foxes on San Miguel Island were conducted by Laughrin in the early 1970s (Laughrin 1973). Trap success (number of fox captures per available traps) was high (43%) and Laughrin concluded that island fox populations were stable at 2.7 foxes/km^2, although this may be an underestimate. In the late 1970s, the island foxes on San Miguel had an average density of 4.6 foxes/km^2 for a total estimated population of 151 to 498 individuals (Collins and Laughrin 1979). In 1993 the National Park Service began a long-term monitoring program for island foxes on San Miguel, utilizing standardized island fox mark-recapture methods (Roemer et al. 1994). Adult density on two grids was about 8.0 foxes per km^2 in 1993, and the islandwide estimate was about 300 foxes (Coonan et al. 1998). A third grid was added the following year. That grid, the Dry Lakebed grid, recorded the highest density known of island foxes in 1994 (15.9 foxes/km^2) and the islandwide estimate rose to 450 adult foxes. The annual monitoring documented a substantial decline in island fox populations on San Miguel Island between 1994 and 1999 (Coonan et al. 1998, Coonan et al. 2000, Coonan et al. in prep). During that period the estimated islandwide population steadily and sharply declined, falling to 15 adults in 1999 (Coonan et al. in prep). In 1999, the NPS brought 14 individuals (4 males and 10 females) of this population into captivity, to protect them from further losses to predation and to initiate a captive propagation program. Data from a remote camera survey and from fox sign (scat and tracks) indicate that the only known individual left in the wild on San Miguel is a radio-tagged female (Coonan et al. in prep). One of four pairs of captive foxes produced a litter of two pups in the spring of 2000. The captive San Miguel Island fox population may also be impacted by high parasite loads (Linda Munson, University of California at Davis, unpublished data).

The cause for the decline on San Miguel Island is likely predation by golden eagles (Roemer 1999, Coonan et al. in prep.). The NPS conducted a radiotelemetry study in 1998-1999 to determine mortality causes for the San Miguel Island fox population. Recovered carcasses were necropsied at University of California, Davis. Within four months of the study's inception, six of eight collared foxes had died, and four of those six were predated by golden eagles (Coonan et al. in prep.). An additional eagle-caused mortality occurred the following fall. Cumulative survival over the yearlong study was approximately 10%. Golden eagle feathers were found at two of the kill sites. Two carcasses not fed upon were found to be extensively parasitized by *Uncinaria* sp. and *Angiocaulus* sp.; the latter parasite is not found in other island fox populations.

Santa Rosa Island

Laughrin (1980) surveyed the Santa Rosa Island fox population in 1972, reporting a trapping efficiency of 50.0% and a density of 4.2 foxes/km^2. No other data are available for the Santa Rosa population except for surveys conducted in 1998-2000. Based on island size, Roemer et al. (1994) estimated the islandwide population on Santa Rosa to be 1,780 adults. However, recent trapping data as well as anecdotal evidence suggest that Santa Rosa has experienced a decline similar to those on Santa Cruz and San Miguel islands (Roemer 1999). During 132 trap nights in 1998 only nine individuals were captured (10 total fox captures), for a trap success rate of 4.8%. Anecdotal sightings of foxes by park and ranch staff are much less frequent than in previous years. In 2000, the NPS brought 14 island foxes into captivity on Santa Rosa, and eight pups were born in captivity in spring, 2000. Less than 5 island foxes are thought to remain in the wild (T. Coonan, unpubl. data). The trapping efficiency during fox capture for captive breeding was 1.3% (15 fox captures in 1115 trap-nights).

Given the proximity of Santa Rosa to Santa Cruz and San Miguel Islands, and the concurrent timing of the decline, golden eagle predation is the likely cause of the decline on Santa Rosa Island (Roemer 1999).

Santa Cruz Island

Santa Cruz Island is the largest of the Channel Islands and has supported the highest known densities of island foxes in the past (Laughrin 1973). Laughrin (1971) estimated the island fox population of Santa Cruz island to be approximately 3000 individuals. Average density between 1973 and 1977 was 7.9 foxes/km^2 (Laughrin 1980). Islandwide estimates extrapolated from annual island fox densities on two grids suggest that the population decreased from a high of approximately 1,000-1,300 in 1993 to its current estimated size of 80-130, and trapping efficiency in 1998 was 2.9% (Roemer et al. 1994, Roemer 1999, G. Roemer, University of California, Los Angeles, pers. comm.).

The population decline on Santa Cruz was likely caused by golden eagle predation (Roemer 1999). From August 1993 to September 1995, golden eagles were linked to 19 of 21 fox mortalities on the western end of Santa Cruz Island. At the end of the study period, the study population of foxes had been entirely extirpated. The island-wide decline is believed to be a consequence of hyperpredation (Roemer et al. in review).). Analogous to apparent competition (Holt, 1977), hyperpredation occurs when a prey species that can sustain high predation rates subsidizes the extinction of another prey species by acting as an alternate food resource for a shared predator (Courchamp, Langlais & Sugihara, 1999). In this case, the presence of an exotic omnivore, the feral pig, enabled eagles to colonize the islands, increase in population size, and overexploit the unwary fox. In addition to the evidence amassed at the fox carcasses, this premise was supported by an increase in golden eagle sightings on the northern Channel Islands, the recent discovery of the first golden eagle nest recorded for the Channel Islands that contained remains of foxes and piglets and by a logistic model of hyperpredation that showed that pigs would have been necessary to support a large, resident eagle population (Roemer 1999, Roemer et al. in review). The model indicates that as few as six golden eagles could have driven the fox population to current low levels (Roemer et al. in review). As mentioned above, 14 eagles have been translocated from Santa Cruz Island.

Santa Catalina Island

Santa Catalina Island has a large human population, a large population of domestic dogs, and the highest degree of activity and accessibility of the Channel Islands. Island fox numbers on Santa Catalina Island have fluctuated widely over the past 30 years. During surveys from 1972 to 1977, Laughrin (1980) caught only two individuals, and trap success was 3.0%, although Propst (1975) caught 55 individuals for a trap success of 11%. Between 1988 and 1991, average density increased, ranging from 2.6 to 12.7 foxes/km^2 (Garcelon et al. 1991). The Santa Catalina Island fox population increased to an estimated 1,342 foxes by 1994 (Roemer et al. 1994).

Recently, Santa Catalina Island foxes have experienced a catastrophic decline, thought to be due to the introduction of canine distemper to the island fox population on the eastern portion of the island (Timm et al. 2000). A narrow isthmus separates the large eastern portion of Santa Catalina Island from the small west end, and this has apparently served as a barrier to canine distemper virus. Trap success on the eastern side dropped from 26.0% in 1998 to 1.0% in 1999 and 2000, while remaining stable at approximately 36.0% on the western portion. One deceased and two live island foxes recovered from the eastern portion of the island tested positive for canine distemper virus, constituting the first positive record of canine distemper in island foxes (Timm et al. 2000). Field vaccination of wild foxes, translocation of juvenile foxes from the west end to the eastern portion, and captive propagation of west end foxes for release in the east are all underway to mitigate the effects of canine distemper virus.

San Clemente Island

Island fox populations on San Clemente Island have been adversely affected by a history of severe overgrazing, past use as a bombing range, and a widespread feral cat problem (Laughrin 1973). The earliest density estimate was 4.2 foxes/km^2 (Laughrin 1973). Wilson (1976) fox density to be 14.6 foxes/mi^2 and island-wide population size to be 2000 foxes, but these numbers are most likely overestimates (G. Roemer, University of California, Los Angeles, pers. comm.). Population sampling between 1988 and 1991 found densities of between 4.8 and 9.1 foxes/km^2 (Garcelon et al. 1991). Roemer et al. (1994) found similar densities and estimated an island-wide population of 1003 foxes. This may be an overestimate, as Garcelon (1999) estimated that the island fox population on San Clemente has ranged between 506 and 875 individuals for the past ten years, and Thompson et al. (1998) cautioned that grid trapping data may overestimate foxes up to 40 percent. Current population size may be about 680 adult foxes, and the population may be undergoing a long-term, gradual decline (see Appendix B of this plan).

The Navy initiated predator management to protect the federally endangered San Clemente loggerhead shrike (*Lanius ludovicianus mearnsi*) in 1992. As part of this program, the Navy initially focused on non-native predators (cats and rats), but in 1999 implemented control measures for native predators as well, including the island fox (Department of the Navy 1999). In 1999, the Navy euthanized 13 foxes and relocated 15 to zoos as part of this program (Garcelon 1999). The Navy has since discontinued euthanizing island foxes. Feral cats exist on the island in high densities (Phillips and Schmidt 1997) and could be competing with island foxes for prey.

San Nicolas Island

Between 1971 and 1977, island fox densities on San Nicolas Island averaged 1.2 foxes/km^2 (Laughrin 1980). During the late 1970s, island fox numbers decreased with the termination of a supplemental feeding program (Laughrin 1980). An increase in the feral cat population on the island was concomitant with the island fox decline (Kovach and Dow 1982). Following the initiation of a cat eradication program in the 1980, fox numbers increased from approximately 120 to 600 foxes in four years (Kovach and Dow 1985). Kovach and Dow (1985) estimated the carrying capacity of the island to be approximately 600 individuals. Island fox numbers densities are currently thought to be high on San Nicolas Island, (Smith 1990, Grace Smith, Department of the Navy, pers. comm. 1999). Mark-recapture sampling in summer, 2000, yielded high densities, a population structure skewed toward adults, and a population estimate of 734 adults (G. Roemer, University of California, Los Angeles, unpubl. data).

Threats to the Species

The Present or Threatened Destruction, Modification, or Curtailment of its Habitat or Range

Habitat on all islands occupied by island foxes has been heavily impactred by livestock grazing, cultivation, and other disturbance. A century and a half of overgrazing by non-native herbivores (sheep, goats, rabbits, deer, elk, cattle, pigs, and horses) has resulted in substantial impacts to the soils, topography, and vegetation of the islands (Johnson 1980, Coblentz 1980, Clark et al. 1990, Peart et al. 1994, O'Malley 1994). One result of overgrazing has been the replacement of much of the native coastal sage scrub, chaparral, and oak woodland habitats with other vegetation, especially non-native annual grasses (Brumbaugh 1980, Clark et al. 1990, Klinger et al. 1994). Annual grasslands constitute less preferred habitat for island foxes (Laughrin 1977) and do not provide cover from predators such as golden eagles (Roemer 1999). The California Department of Fish and Game (CDFG), in recommending the retention of the island fox' classification as threatened under state law, cited the continued habitat degradation from herbivorous mammals on Santa Rosa, Santa Cruz, Santa Catalina, and San Clemente islands (CDFG 1987). Since that time, alien species removal programs have eradicated or reduced the introduced herbivore populations on many islands. Remaining alien herbivores include pigs on Santa Cruz Island, deer and elk on Santa Rosa Island, and pigs and goats on Santa Catalina Island (Table 1).

Even after the removal of non-native grazers on some islands, habitat recovery is slow (Hochberg et al. 1979), and threatened by the spread of non-native plants that were able to gain a foothold during the ranching era. These exotic species continue to invade and modify island fox habitat resulting in lower vegetative diversity, less diverse habitat structure, and reduced food availability. The replacement of native shrub communities by annual grasslands has also reduced protective cover for island foxes, making them more vulnerable to predation (Roemer 1999, Coonan et al. in prep.)

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Although island foxes were used in the past for pelts and ceremonial uses by Native Americans (Collins 1991b), island foxes are not currently exploited for commercial, recreational, scientific, or educational purposes.

Predation

Recent island fox declines on San Miguel, Santa Cruz, and Santa Rosa islands have been attributed to predation by golden eagles (Coonan et al. in prep, Roemer 1999, Roemer et al. in review). Roemer (1999) linked 19 of 21 island fox mortalities on Santa Cruz Island between 1993 and 1995 to golden eagles. On San Miguel Island, 5 of 7 mortalities of radio-collared foxes were attributed to golden eagle predation during 1998-1999 (Coonan et al. in prep). This level of golden eagle predation is unnatural. Until the late 1990's, golden eagles never bred on the Channel Islands; their recent appearance is likely due to a prey base, feral pigs that was not present prehistorically. The absence of bald eagles which bred historically on the islands and whose presence may have kept golden eagles away, is another contributing factor driving increased golden eagle predation. Moreover, on much of the northern Channel Islands, historic sheep grazing changed the predominant vegetation from shrub to non-native grasslands, which offer much less cover from aerial predators.

Table 1. Non-native mammal species occurring or recently occurring on the Channel Islands.

	Anacapa	Santa Cruz	Santa Rosa	San Miguel	Santa Barbara	Santa Catalina	San Nicolas	San Clemente
Sheep (Ovis aries)	----	----	----	----	----	----	----	----
Feral Goat (*Capra hircus*)						X		----
Cattle (*Bos Taurus)*		----	----			----		----
Pigs (*Sus scrofa*)		X	----			X		----
Rabbits (*Oryctolagus cuniculus*)					----			
Feral Horse (*Equus caballus*)		----						
Black Rat (*Rattus rattus*)	X			X		X		X
Norway rat (*Rattus norvegicus)*						X		
Domestic dogs (*Canis familiaris*)								
Feral Cat (*Felis catus*)	----				----	X	X	X
Bison (*Bison bison)*						X		
Mule Deer (*Odocoileus hemionus)*			X			X		
Donkey/Burro (*Equus asinus*)				----				
Elk (Cervus elaphus)			X					
House mice (*Mus musculus)*						X		X
Black Buck Antelope (*Antelope cervicapra)*						X		
Barbary sheep *Ammotragus lervia*)						----		

---- Occurred formerly
X Occurs now as feral or non-domestic population

The current level of golden eagle activity on the northern Channel Islands is historically unprecedented (L. Laughrin, University of California, Santa Barbara, unpubl. data). Golden eagles were known to occasionally visit the islands but never to establish residence (Diamond and Jones 1980; Jones and Collins in prep.). The first known active golden eagle nest from the Channel Islands was located on Santa Cruz Island in 1999 (Sam Spaulding, National Park Service, pres. comm., Brian Latta, Santa Cruz Predatory Bird Research Group, pers. comm; G. Roemer, University of California, Los Angeles, pers. comm.). Island fox remains along with the remains of feral piglets (*Sus scrofa*), ravens (*Corvus corax*), Brandt's cormorants (*Phalacrocorax pencillatus*), and western gulls (*Larus occidentalis*) were found in the nest.

In September 1999, surveys by the Santa Cruz Predatory Bird Research Group identified 12 golden eagles with the possibility of five breeding pairs on Santa Cruz Island. Santa Cruz Island is the main nesting and roosting location for golden eagles on the northern Channel Islands, golden eagles may nest on Santa Rosa Island (B. Latta pers. comm. 2000). Golden eagles breeding on Santa Cruz Island are thought to “commute” to Santa Rosa and San Miguel islands to feed, where eagles have fewer alternative prey species to island foxes (i.e., no feral pigs as on Santa Cruz Island) and foxes have less vegetative cover to hide them from avian predators (Roemer 1999). Between November, 1999 and March, 2001, 14 golden eagles were captured from Santa Cruz Island and relocated to northern California to reduce further island fox mortality. As of March, 2001, seven golden eagles remain on Santa Cruz Island Three nesting pairs and a subadult), and occasional eagle visits to Santa Rosa and San Miguel are likely as well (B. Latta, Santa Cruz Predatory Bird Research Group, pers. comm.)
.

Before golden eagles started utilizing the northern Channel Islands in the 1990s, the only known predator of island foxes were red-tailed hawks (*Buteo jamaicensis*), which only preyed on young island foxes (Laughrin 1973, Moore and Collins 1995). The docile and inquisitive nature of the island fox (Laughrin 1977) suggests an evolutionary history lacking predation (Carlquist 1974).

The recent colonization of the northern Channel Islands by golden eagles is likely a combination of two factors: 1) introduction of exotic mammals on the northern Channel Islands constituting an historically unprecedented prey base, and 2) the recent absence of bald eagles from the islands as a result of DDT poisoning (P. Collins, Santa Barbara Museum of Natural History, pers. comm. Kiff 1980). Historically, the depauperate vertebrate island fauna would have provided little prey for golden eagles, which rely on a diet of small terrestrial vertebrates. Before the ranching era, transient golden eagles landing on the islands would have little prey to encourage them to establish permanent residence. Furthermore, nesting bald eagles would have discouraged foraging golden eagles from establishing residence by aggressively defending their already established territories. Bald eagles are represented in the prehistoric fossil record of the northern Channel Islands (Guthrie 1993) and bred there until 1960 when nest failures as a result of DDT contamination extirpated them from the northern Channel Islands (Kiff 1980).

Roemer et al. (in review) modeled interspecific population dynamics using predation rates of golden eagles estimated from time-energy budgets on Santa Cruz island, to determine if the precipitous decline in island foxes could be attributed to predation alone. Their model showed that in the presence of a large pig population, a population leveling off at seven eagles could cause the extinction of the Santa Cruz Island fox population in 6.7 to 11.5 years depending on the prey preference of the eagles. The observed declines actually occurred over a 6 year period. Their model also confirms that a golden eagle population as large as the one resident on Santa Cruz Island (13 to 18 eagles) could not have been sustained without pigs as a supplemental food.

Disease

On Santa Catalina Island, the large sudden decline in island foxes has been attributed to canine distemper, most likely brought to the island by a domestic dog (Timm et al. 2000). The steep and sudden pattern of decline on Santa Catalina Island is more indicative of a disease outbreak rather than the slower decline due to predation seen on the northern Channel Islands (Timm et al. 2000). The evidence for disease comes from three sources. First, the population decline on Santa Catalina Island is of a similar magnitude (90%) as on the northern Channel Islands, but has occurred within one year rather than the steady 6-year decline seen on San Miguel and Santa Cruz islands. Second, the declines on the northern islands are island-wide, while the geographically restricted western population on Santa Catalina Island has remained healthy;. Finally, sick foxes have been seen on Santa Catalina Island but not on the northern Islands (G. Roemer, University of California, Los Angeles, pers. comm.).

Two healthy adult foxes caught on the east end of Santa Catalina Island in 1999 tested positive for antibodies to canine distemper, constituting the first positive records of canine distemper in island foxes. A necropsy performed on another island fox identified the cause of death as canine distemper (Timm et al. 2000). No island foxes tested positive for exposure to canine distemper in a previous comprehensive serologic survey of all islands (Garcelon et al. 1992), nor did any foxes from San Clemente, Santa Cruz or San Miguel test positive for CDV during the period

(1994 – 1997) of the fox decline on the northern islands (Roemer et al. in review). The absence of antibodies to canine distemper virus in any island foxes implied that either the virus had never been introduced to the islands, or the species is highly susceptible to the virus and none survive infection. Because the closely related mainland gray fox is highly susceptible to canine distemper virus, island foxes likely have high susceptibility as well (Garcelon et al. 1992).

All island fox populations have been surveyed for other canine diseases and parasites. Although island foxes are known to carry antibodies against a variety of canine diseases, none of these could explain the type or geographic distribution of the observed decline on the northern Channel Islands (Garcelon et al. 1992, Coonan et al. 2000, Roemer 1999, Roemer et al. in review). The most common antibodies found in island foxes are against canine adenovirus and canine parvovirus, while titers against canine herpesvirus, coronavirus, leptospirosis and toxoplasmosis have been recorded at low levels (Garcelon et al. 1992, Coonan et al. 2000, Roemer et al. in review). Seroprevalence to canine adenovirus was similar before and after the population crashes on these islands. Antibodies for parvovirus were detected from a small number of samples from 1994, but not detected in 1995 or 1997 samples (Coonan et al. 2000). Canine adenovirus may be enzootic in the island fox populations (Garcelon et al. 1992), with little effect on individual health. Canine parvovirus has been found in other wild canids and can result in mortality of pups, prior to emergence from the den (Garcelon et al. 1992).

Canine heartworm (*Dirofilaria immitis*) has been documented serologically in four of the six island fox subspecies (*U. l. littoralis*, *U. l. santacruzae*, *U. l. santarosae,* and *U. l. dickeyi*; Roemer et al. 2000a). Despite the high seroprevalence of heartworm in these populations (58-100% in 1997-98) heartworm is not thought to be responsible for the decline of island foxes, for several reasons. First, seroprevalence on San Nicolas Island, where the population is stable and dense, is higher than on Santa Cruz Island, where the population is decreasing (Roemer et al. 2000a). Second, heartworm was detected in all four subspecies in or before 1988, pre-dating the population declines, and seroprevalence in the San Miguel population was high in 1994, when densities on that island reached the highest levels ever recorded for island foxes. Last, necropsy results have found few adult worms in the hearts of island foxes and no evidence of heartworm disease (L. Munson, University of California, Davis, pers. comm; Roemer 1999). However, heartworm may have contributed to mortality in older foxes (Roemer et al. 2000a), exacerbating the conservation crisis for the island fox.

As the recent decline on Santa Catalina Island illustrates, the potential for introduction of canine diseases to all fox populations constitutes a serious threat. Island foxes are vulnerable to canine diseases, and the introduction of a disease greatly increases the risk of extinction for these small populations (see Appendix B). Dogs occasionally come ashore on park islands, despite the existing prohibition against pets (see below).

The Inadequacy of Existing Regulatory Mechanisms

The primary causes of the decline of the island fox are the degradation of habitat by introduced herbivores, unprecedented and unnatural levels of predation by golden eagles, and the rapid transmission of canine distemper through the Santa Catalina subspecies. Federal, state and local laws have not been sufficient to prevent past and ongoing losses of island foxes.

In 1971, the state of California listed the island fox as rare (a designation later changed to threatened), which means that it may not be taken without a special (i.e., scientific collecting) permit (CRC, Title 14, Section 41). However, this protection applies only to actual possession or intentional killing of individual animals, and affords no protection to habitat. State law does not require Federal agencies to avoid or compensate for impacts to the island fox and its habitat.

There are currently no regulatory mechanisms specifically designed for the protection of island foxes on the four islands that are federally managed, except for prohibitions against bringing pets to lands of Channel Islands National Park, and to U.S. Navy lands. Section 2.15 of the superintendent's compendium prohibits pets from all park islands, except for guide dogs for visually impaired persons. However, dogs have been used to eradicate pigs from Santa

Rosa and Santa Cruz Islands, and the NPS intends to use dogs in future pig removal efforts on Santa Cruz Island. Additionally, prohibitions against bringing dogs ashore are difficult to enforce and violations are known to occur. Boaters have been observed bringing pets onshore to all three northern Channel Islands with island fox populations. On Santa Catalina Island, health certificates or quarantines are not necessary to bring domestic pets to the islands, thus exposing island foxes to increased risk of disease. On Santa Rosa Island, the current special use permit for the commercial hunt operation allows for island-resident employees of the permittee to have “ranch dogs” on the island. Dogs owned by a non-island resident permittee or guest are allowed in the park for periods not to exceed 30 days at a time. All dogs permitted under the special use permit must have proof of vaccination in compliance with Santa Barbara County regulations (rabies only required).

Several Federal laws apply to the management of National Park Service (NPS) and Department of the Navy (Navy) lands. These laws and guidelines include the National Environmental Policy Act (NEPA) and the Endangered Species Act. NPS management is further dictated by Department of the Interior policies and National Park Service policies and guidelines, including NPS guidelines for natural resources management (NPS 1991), the Channel Islands National Park Management Plan (NPS 1985), and the National Park Service Organic Act (16 U.S.C. l 2 3, and 4). Both NPS and the Navy have adequate authority to manage the land and activities under their administration to benefit the welfare of the island fox. Steps are being taken to control feral cats on San Clemente and San Nicolas islands and decrease predation by relocating golden eagles from the northern Channel Islands. However, in some cases because of conflicting management concerns, other priorities and lack of funding, conservation efforts are not proceeding as quickly as necessary. In addition to removing golden eagles, their prey base must be removed to prevent them from recolonizing the islands. Santa Cruz Island is currently occupied by a large feral pig population (estimated at approximately 3-5000 individuals). The Nature Conservancy and NPS are planning an island-wide pig eradication program. The program will start in 2003 but may take as long as six years to complete.

San Miguel Island is owned by the U. S. Navy, but NPS has responsibility for management of the natural, historic, and scientific resources of San Miguel Island through a Memorandum of Agreement (MOA) originally signed in 1963, an amendment signed in 1976, and a supplemental Interagency Agreement (IA) signed in 1985. The MOA states that the “paramount use of the islands and their environs shall be for the purpose of a missile test range, and all activities conducted by or in behalf of the Department of the Interior on such islands, shall recognize the priority of such use” (Department of the Navy 1963). In addition to San Miguel Island, Santa Cruz and Santa Rosa lie wholly within the Navy's Pacific Missile Test Center (PMTC) Sea Test Range. The 1985 IA provides for PMTC to have access and use of portions of those islands, for expeditious processing of any necessary permits by NPS, and for mitigation of damage of park resources from any such activity (Department of the Navy 1985). To date, conflicts concerning protection of sensitive resources on San Miguel Island have not occurred.

Federal protection of golden eagles by the Bald and Golden Eagle Protection Act of 1962, as amended, has increased the golden eagle population on mainland California (B. Walton, Santa Cruz Predatory Bird Research Group, pers. comm.). This population expansion has allowed golden eagles to expand their range. The protections extended to golden eagles limit management alternatives to protect island foxes from them. Lethal removal of golden eagles would require a depredation permit from the U.S. Fish and Wildlife Service. Such a permit would allow golden eagles to be taken by firearms, traps, or other suitable means except by poison or from aircraft (50 CFR Ch. 1, Part 22.23).

California State law (Food and Agricultural Code 31752.5) prohibits lethal control of feral cats unless cats are held for a minimum of six days. This law prevents the Santa Catalina Island Conservancy from taking steps to eradicate feral cats on the island, as it does not have adequate facilities to hold cats.

Other Natural or Manmade Factors Affecting its Continued Existence

Several other factors, including competition from introduced species, and stochastic environmental factors may have negative effects on island foxes and their habitats.

Competition with feral cats. CDFG, in recommending the retention of the threatened classification of the island fox under state law, cited the presence of competition with feral cats on Santa Catalina, San Nicolas, and San Clemente islands (CDFG 1987). The effects of cats on island foxes are unknown and may differ among islands. Island fox population decreases on San Nicolas Island were accompanied by a concomitant increase in feral cat populations (Laughrin 1978). Feral cats outweigh island fox by an average of 2 to 1 and may negatively affect island foxes by direct aggression, predation on young, disease transmission, and competition for food resources (Laughrin 1978). Feral cats have been found to displace island foxes from habitats on San Nicolas Island (Kovach and Dow 1985). San Nicolas and San Clemente Island managers plan to continue or resume feral cat control programs, but feral cats are extremely difficult to eradicate, requiring ongoing yearly programs to keep numbers controlled (Phillips and Schmidt 1997). No feral cat control exists on Santa Catalina Island, due to resistance to lethal control from the residents of the island as well as the existence of local ordinances prohibiting such.

Lack of genetic variability. As a population becomes genetically homogenous, its susceptibility to disease, parasites, and extinction increases (O'Brien and Evermann 1988) as its ability to evolve and adapt to environmental change is diminished (Templeton 1994). The four island fox subspecies that have suffered large declines could be at risk of having reduced genetic variability due to the bottleneck in their populations that has occurred. In fact, at least one microsatellite locus previously variable in the San Miguel fox population is now fixed in the captive population, suggesting that genetic variation has been reduced (M. Gray and E. Torres, California State University, Los Angeles, unpubl. data). Further, the San Nicolas Island fox subspecies has been found to have an unusually low degree of genetic variability, being monomorphic in allozyme, hypervariable minisatellite and microsatellite DNA, and mitochondrial DNA (Gilbert et al. 1990, Wayne et al. 1991, Goldstein et al. 1999). The average percent difference in DNA fingerprints of San Nicolas Island foxes was 0.0%, most likely a result of a major bottleneck at some point in time (Gilbert et al. 1990). Although the San Nicolas Island subspecies of island fox currently exists at high densities, the precipitous declines seen on other islands coupled with the extremely low genetic variability may put this subspecies at risk.

Stochastic environmental factors. Reduced population size makes island fox populations more vulnerable to stochastic events such as drought or wildfires that could cause or hasten extinction (see Appendix B). The extremely small island fox population sizes on San Miguel, Santa Rosa and Santa Cruz islands put those populations at extremely high extinction risk. For example, of the 14 island foxes brought into captivity on San Miguel Island, only four were male. This skewed sex ratio may reduce the recovery ability of the species, because island foxes typically form long-term pair bonds and unpaired females have never been recorded to raise a litter. Because the island fox is distributed on small islands it is more subject to the effects of environmental perturbations and decline of birth rates due to low densities (i.e., Allee effects; Allee 1931) than species occurring on the mainland. Island endemic species have high extinction risk due to isolation and small population sizes (MacArthur and Wilson 1967).

Road mortalities. The fearless nature of island foxes coupled with relatively high vehicle traffic on the southern Channel Islands results in a number of vehicle collisions each year. Death by collision with vehicles is the largest known source of mortality on San Nicolas and San Clemente islands, taking approximately 20-40 foxes on San Nicolas per year (G. Smith, U. S. Navy, pers. comm.) and and a minimum of 26 foxes between the years 1991 and 1995 on San Clemente Island (Garcelon 1999). Vehicle collisions likely cause a comparable number of deaths on Santa Catalina Island, although no records are kept. Vehicle collisions on the northern Channel Islands are less common due to low traffic volume and the rough unpaved nature of most roads, which reduces vehicle speed.

Table 2. Management/ownership of islands upon which island foxes occur.

Island	Federal[1]	Ownership Conservancy	Private
San Miguel[2]	USN/NPS – 100%		
Santa Rosa	NPS – 100%		
Santa Cruz	NPS - 24%	76%	
San Nicolas	USN – 100%		
Santa Catalina		88%	12%
San Clemente	USN – 100%		

[1]NPS = National Park Service
USN = U. S. Navy
[2]San Miguel Island is owned by the U. S. Navy and managed by the National Park Service

Affected Agencies, Landowners and Partners

Lands inhabited by island foxes are owned by four major landowners: the National Park Service (Department of the Interior), the U.S. Navy (Department of Defense), The Nature Conservancy, and The Santa Catalina Island Conservancy (Table 2). Fifty-six percent of the land is owned by the federal government, 41% by conservancies, and an additional 3% is owned by other private landowners.

Other agencies with management authority over the island fox include the state of California, which has authority for management of wildlife on non-federal lands. The island fox is currently state-listed as threatened. Although the species is not listed as endangered or threatened under the federal Endangered Species Act, the U.S. Fish and Wildlife Service has been involved in developing recovery actions, and has partially funded golden eagle removal.

The bulk of the current knowledge base regarding the evolution, ecology and population biology of island foxes has been amassed by researchers from California institutions, including University of California (Los Angeles, Davis, Santa Barbara, Santa Cruz), California State University (Los Angeles), and the Santa Barbara Museum of Natural History. Golden eagle removal is being conducted by the Santa Cruz Predatory Bird Research Group, affiliated with University of California (Santa Cruz). The non-profit Institute for Wildlife Studies, located in Arcata, California, has conducted island fox monitoring, research and management for over 15 years, and has been involved in projects on all of the Channel Islands. The IWS is currently a cooperator or contractor for island fox projects with the National Park Service, the U.S. Navy, the Santa Catalina Island Conservancy, and The Nature Conservancy. Sound and functional collaboration with researchers has been, and will continue to be, critically important for island fox management efforts.

The development and implementation of the emergency island fox recovery efforts has thus far been a cooperative effort, utilizing expertise from agencies, non-profit institutions, academia, zoological institutions, and the conservation community (see Consultation and Coordination). The diverse expertise was required in order to quickly evaluate the island fox situation and develop appropriate recovery actions. Such a team approach is typical for official recovery actions for federally listed species, but there is no guarantee that the species, or any of the subspecies, will be listed under the Federal Endangered Species Act. Nonetheless, island fox recovery is likely to require up to a decade of intensive management actions, and a recovery team approach will be required to insure that recovery actions are appropriate, are prioritized, and are coordinated among the different landowners and partners involved.

Within Channel Islands National Park, lands on which island foxes occur are owned and/or managed by three entities. San Miguel Island is owned by the U.S. Navy and managed by the NPS under cooperative agreement. The NPS owns and manages Santa Rosa Island. The NPS owns and manages a quarter of 62,000-acre Santa Cruz Island, and the remainder is owned by The Nature Conservancy. The NPS and The Nature Conservancy cooperate fully on resources management and research issues, via cooperative agreement (CA1443GA8120-99-004, signed November 11, 1999). As such, TNC is considered a full partner in island fox research and recovery actions on Santa Cruz Island. Currently, TNC is partially funding golden eagle removal on that island, as well as a study of island fox distribution, abundance, and survivorship. The TNC and NPS are also cooperating on development of a feral pig eradication plan for Santa Cruz Island.

Guidelines for Management

Guidance for development of this plan is found in various laws, NPS management policies and guidelines, and previous park planning efforts. The following is a discussion of the influence of such factors on island fox management at Channel Islands National Park.

Guidance for Natural Resources Management

The following is a summary of the laws and NPS policies that guide resources management at Channel Islands National Park, as in other NPS units.

Protection of park wildlife is mentioned specifically in the enabling legislation for Channel Islands National Park (Public Law 96-199), which established the park in order to “protect the nationally significant natural, scenic, wildfire, marine ecological, archaeological, cultural, and scientific values of the Channel Islands.” Further guidance for natural resources management is provided by the history of legislation affecting the National Park Service, and by servicewide policies.

The 1916 NPS Organic Act, (16 USC 1 et seq.) directed that NPS lands be managed to conserve the resources contained within “in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.” The Redwoods Act of 1978 (16 USC 1a-1) reaffirmed this principle. In general, these two statutes confer upon the Secretary of the Interior the discretion to determine how best to protect and preserve park resources. NPS management policies (NPS 2001a) reiterates that preserving park resources and values unimpaired is the core, or primary, responsibility of NPS managers.

Since the establishment of Yellowstone National Park in 1872 and the subsequent founding of the National Park Service in 1916, the philosophy of natural resources management has gradually evolved from such simple concepts as protection from poaching to the complexities of comprehensive ecosystem management in a regional and global context (NPCA 1989).

In 1961, the Secretary of the Interior convened a blue-ribbon panel to evaluate how NPS should manage large mammals and other animals. The resultant report (Leopold et al. 1963) clearly directed NPS toward ecosystem management, which is the management of all components of an ecosystem as a whole, rather than single-species management. The Leopold Commission promoted the notion that national parks should be managed as “vignettes of primitive America” in order to preserve, to the extent possible, the biota that existed or would have evolved had European humans not colonized North America. Although this has been interpreted by some as a call for “hands-off” management of a static primitive condition or scene, the Leopold Commission actually promoted an aggressive stewardship of parklands with “hands-on” management techniques, and perpetuation of dynamic, evolving ecosystems. For example, the report called for restoration of natural fire regimes in parks.

More recent work has built upon the findings of the Leopold Commission regarding resources management in NPS units. Parsons et al. (1986) state that the principal aim of National Park Service resource management in natural areas is the unimpeded interaction of native ecosystem processes and structural elements. In 1989, NPS convened a blue ribbon panel to assess the role of resource management and research in the future of the national parks. The resulting report (NPCA 1989) validated the findings of the Leopold Commission, affirming that the focus of park management should be to maintain or restore native biota and ecosystems and to resist establishment of alien organisms. Where possible, ecosystem management should attempt to preserve natural processes operating at a scale consistent with the evolution of the ecosystem being managed. The report recommended that NPS move well beyond static scene management to provide stewardship for the elements and processes contained in parks.

National Park Service management policies (NPS 2001a) reflect the development of ecosystem management concepts. In part, the policies state that natural resources should be managed with a concern for fundamental ecological processes as well as for individual species and features:

> The Service will not attempt to solely preserve individual species (except threatened or endangered species) or individual natural processes; rather it will try to maintain all the components and processes of naturally evolving park ecosystems, including the natural abundance, diversity and genetic and ecological integrity of the plant and animal species native to those ecosystems (NPS 2001a, p. 28)

Management of Rare Species

The island fox is state-listed as threatened, and in the future it may be listed by U.S. Fish and Wildlife Service under the federal Endangered Species Act, or it may become a candidate species. Guidance for the management of the species under those designations is provided by agency policies and guidelines, as well as by legislation.

National Park Service management policies (NPS 2001a) set forth the basic responsibilities of the National Park Service in regard to management of federally listed endangered and threatened species. The NPS is required by law to comply with the Endangered Species Act of 1973, as amended, which pertains to species already listed as threatened or endangered. Section 7 of the Act requires federal agencies to consult with the U.S. Fish and Wildlife Service if their activities may affect listed species, and requires the agencies to develop programs for the conservation of listed species. However, NPS management policies also speak to consideration of candidate species by parks by calling on parks to:

- Cooperate with other agencies, states, and private entities to promote candidate conservation agreements aimed at precluding the need to list species.
- Conduct actions and allocate funding to address endangered, threatened, proposed and candidate species. (NPS 2001a, p. 35)

The management policies extend similar protections to state-listed species, such as the island fox:

> The National Park Service will inventory, monitor, and manage state and locally listed species in a manner similar to its treatment of federally listed species, to the greatest extent possible…and will include consultation with lead federal and state agencies as appropriate (NPS 2001a, p. 35).

The Natural Resources Management Guideline for the NPS (NPS-77; NPS 1991) provides further guidance for the management of both candidate and listed species. The guideline lists the following major program objectives, many of which include consideration of candidate species:

1) Inventory and monitor sensitive candidate and listed species.

2) Manage endangered, threatened, and candidate species, and their critical habitats, in conformance with the Endangered Species Act of 1973, as amended; recovery plans and other appurtenant documents.

3) Ensure that park operations do not adversely affect endangered, threatened, candidate, or sensitive species and their critical habitats within the park.

4) To the extent possible, ensure that activities, projects or programs outside the park do not adversely affect endangered, threatened, candidate, or sensitive species and their critical habitats within the park.

5) To the fullest extent possible, integrate park management actions with other federal, state and private recovery efforts.

6) Ensure appropriate consideration of federal and state-listed species and other special status species in all plans and NEPA documents.

7) Encourage NPS involvement on recovery teams as appropriate.

8) Design and implement research relevant to the preservation of candidate, rare, sensitive, and listed species.

9) Thoroughly document recovery actions and considerations.

Thus, candidate and listed species are treated similarly in both NPS management policies and guidelines for natural resources management. The guidelines further define NPS responsibility for candidate species:

> Management of these [candidate and state-listed] species should, to the greatest extent possible, parallel the management of federally listed species (NPS 1991, Ch. 2:275).

The guideline states unequivocally that “Management options must place highest priority on identifying and removing the threat of extinction” (NPS 1991, Ch. 2:273). Nonetheless, in setting forth the general goals for NPS recovery efforts for threatened and endangered species, the guideline emphasizes the need to go beyond mere habitat protection to the active recovery of species:

> The goal of endangered and threatened species recovery efforts is generally to increase populations and secure sufficient, suitable habitat to “recover” the species to acceptable levels (i.e., pre-decline or some other designated level). Endangered and threatened species, therefore, cannot simply be preserved through general habitat protection; they must be actively managed for recovery. If we only continue to preserve, those species may simply continue to decline because their habitats may no longer be suitable for survival, reproduction, and recruitment. (NPS 1991, Ch. 2:272).

The guideline also stresses that recovery actions and other management actions for threatened and endangered species must be accomplished in an ecosystem context:

> Management affects the distribution, abundance, and ecological relationships of and among species...The NPS's goal is the long-term preservation of species and their ecological role and function as part of a “natural ecosystem”. (NPS 1991, Ch. 2:273).

The natural resources management guidelines also direct the NPS to join in cooperative partnerships with U.S. Fish and Wildlife Service and other agencies in order to achieve the goals of the endangered and threatened species management program:

> Management of candidate, threatened, and endangered species recovery efforts should be coordinated and integrated with other federal and state agencies to ensure that recovery efforts achieve maximum effectiveness and efficiency. The NPS should participate on recovery teams for those species that occur in units of the National Park System. Development of or participation in cooperative agreements, interagency agreements, memoranda of understanding, and coordination meetings is encouraged if such development or participation contributes toward meeting recovery objectives. Involvement of nongovernmental entities may be appropriate for many recovery efforts. (NPS 1991, Ch.2:276).

Finally, the guidelines define the responsibilities for managing candidate, threatened, and endangered species at the park level:

> The superintendent ensures that park operations do not adversely affect listed, candidate, rare and sensitive species, their habitats, or recovery efforts within the park. He/she also ensures consideration of these species in all other park plans and NEPA documents and integrates park management actions with those of federal and state agencies. (2:278).

The NPS management policies (NPS 2001a) also direct the service to protect the full range of genetic types native to organisms in the parks.

In summary, NPS management policies and guidelines for natural resources management:

- establish the affirmative responsibility of the NPS, and the individual park, for managing both listed and candidate species;

- stress that management actions should emphasize removal of threats, but also include active recovery efforts, and that management should be done in an ecosystem context;

- direct parks to integrate park recovery efforts with those of other agencies, and participate in recovery team activities.

Park Planning Documents

In addition to the guidance provided by servicewide guidelines, management of National Park Service units is guided by planning documents developed specifically for each unit. *General management plans* are broad, long-range strategies for development and management of parks. Other, more specific plans tier off of general management plans. These include *resources management plans*, which address natural and/or cultural resources management issues in parks.

The park's general management plan (NPS 1980, 1985) generally reiterate the park's affirmative responsibilities under the federal Endangered Species Act. The natural resource management portions of the plan were developed in 1980, prior to the acquisition by NPS of Santa Rosa Island and portions of Santa Cruz Island, and prior to the decline of the island fox on park lands. Nonetheless, the plan specifically states that the management objective for island foxes was to maintain the good health of the island fox population on San Miguel (NPS 1980, p. 57). The plan called for the following actions: monitor the health and status of the fox population to detect any change, and encourage research by others into the biology of the San Miguel Island fox.

The park's resources management plan was recently revised (NPS 1999). The plan reiterates the general management plan goal for foxes on San Miguel, and states that a general goal is to understand, restore, and protect the natural ecosystems and cultural resources for which Channel Islands National Park was established. An additional goal is to promote the recovery of species that have been reduced in abundance and distribution by human activities. One of the highest priority projects listed in the plan is to implement recovery actions for the island fox.

Need for the Action

Without immediate protection and restoration, it is unlikely that the island fox will continue to persist over a significant portion of its range within Channel Islands National Park. Two island fox subspecies are at critically low population sizes (San Miguel at 17 individuals, and Santa Rosa at less than 30), and a third, Santa Cruz, may number less than 100. Outside the park, Santa Catalina's island fox population has declined by 90% in under a year, and the population on San Clemente is also in decline. Total number for the species is approximately 1,300 adults, which is less than 25% of what it may have been in 1993-1994. Recent annual survivorship in the wild is about 10% on San Miguel and less than 20% on Santa Cruz.

Two catastrophic mortality factors, golden eagle predation and canine distemper virus, are currently at work in several island fox populations. Each of those mortality factors is a direct or indirect result of human impacts to the ecosystem of the Channel Islands. Only one subspecies, the San Nicolas island fox, is considered to exist at high density, currently. All fox populations are so low that they are vulnerable to catastrophic mortality factors such as the introduction of canine diseases, and to stochastic events such as fluctuations in climate, and normal fluctuation in survivorship and fecundity. If left unmanaged, two, and possibly four subspecies of island fox will likely decline to extinction within a matter of years.

Existing statutes, agency policy and guidelines, and park planning documents all direct the park to recover island foxes to viable population levels. Specifically, the Park is directed to 1) treat the species essentially as if it were listed under the Federal Endangered Species Act; 2) coordinate recovery actions with other agencies, and participate on recovery teams; 3) reintroduce foxes to areas where they have been extirpated; 4) conserve genetic resources by managing each subspecies as an evolutionarily significant unit; 5) remove the human-caused ecosystem perturbations responsible for the island fox decline, and 6) monitor the health and status of island fox populations. Were the Park not to act to recover island foxes, the extinction of several fox subspecies on park lands would contravene all existing policy and statutes.

Generally, four types of actions are required to recover the species on the northern Channel Islands.

- Action must be taken to reduce or eliminate golden eagle predation, which is the primary mortality source currently working on island fox populations on the northern Channel Islands, and actions need to be taken to insure that canine diseases are not introduced to island fox populations.
- Those subspecies with critically low population sizes need to be augmented via captive propagation.
- An adaptive management program needs to be implemented that will tie future management actions to pre-established monitoring criteria.
- Native ecosystem elements and processes need to be restored to the northern Channel Islands.

Ecosystem restoration is required to ameliorate the perturbations caused by alien species. Current ecological conditions increase the probability that golden eagle predation will be a significant mortality factor for island foxes. Feral pigs inhabit Santa Cruz Island and support migrant, wintering and breeding golden eagles. The NPS and The Nature Conservancy plan to remove feral pigs from Santa Cruz Island, but that effort will not begin until 2003 and may take 6-8 years to complete. Second, bald eagles no longer breed on the northern Channel Islands, and thus no longer act as potential deterrent to golden eagles. The NPS is working to restore bald eagles to the northern Channel Islands, but it may be at least five years following release before adult bald eagles successfully defend territories. Finally, extensive alien annual grasslands on the northern Channel Islands provide much less cover from aerial predators than do native shrublands. The NPS and TNC are taking actions to restore the native plant communities of the islands. Substantial recovery of island vegetation communities is estimated to take several decades.

Part II Recovery Actions

Goals, Objectives and Criteria

The overall *goal* of this plan, and of the ensuing island fox recovery program, is to minimize the threat of extinction for the three island fox subspecies occurring in Channel Islands National Park, thus recovering island fox subspecies to population levels and vital rates which are self-sustaining, or at least require a minimum of management action to maintain. This goal is consistent with National Park Service policy regarding management of natural resources in general, and rare species in particular.

To attain the goal of island fox population recovery, the following *objectives* need to be achieved:

- Remove or minimize mortality factors for all populations, focusing primarily on the human-caused mortality factors of golden eagle predation and canine disease
- Augment wild populations of those subspecies with critically low populations, via captive breeding
- Establish management and monitoring programs to protect wild fox populations
- Restore natural ecosystem elements and processes to the northern Channel Islands

Population recovery *criteria* need to be established to evaluate the effectiveness of recovery actions, and to provide endpoints for recovery. Demographic modeling has been used to develop ranges of vital rates (survivorship, reproductive output, and population size) that are characteristic of increasing fox populations, with minimal chance of extinction (Roemer et al. 2000b; see Appendix B of this plan). The models were based on data from field studies of island foxes on San Miguel, Santa Cruz, and San Clemente Islands. Because population vital rates vary by island (subspecies), island-specific population models were constructed, and therefore recovery criteria are also island-specific.

Demographic modeling was also used to develop an augmentation (captive breeding) schedule and output that would result in wild populations of sufficient size to persist over time.

Target Vital Rates

Although minimum viable population size is an intuitive recovery objective, it is just as important to identify population vital rates that result in stable or increasing populations. The extensive field dataset for island foxes allows the identification of such a set of linked population parameters that result in positive population growth.

Demographic modeling shows that persistence of island fox populations over time depends on favorable values for reproductive output, pup survivorship, and adult survivorship (see Fig. 2 in Appendix B). Island-specific schedules of reproductive output were developed for island foxes. For San Miguel and Santa Cruz island foxes those estimates did not change over time. For San Miguel, those values are an average ratio of 2.1 pups seen per adult female, with 20% of first-year females lactating, and 60% of all other females. For Santa Cruz, the average ratio of pups per adult female was 1.53, percentage of first-year females lactating was 39%, and percentage of adult females lactating was 61%. Assuming similar levels of reproductive output in future wild populations, there is a range of pup and adult survivorship values that will produce populations which are increasing (i.e., populations with r [intrinsic growth rate, or population growth rate] > 1.0) (Table 3). An r > 0 indicates an increasing population, whereas an r < 0 indicates a declining population.

Table 3. Target population sizes and vital rates for island foxes on the northern Channel Islands, based upon demographic modeling (Roemer et al. 2000).

	San Miguel		Santa Rosa		Santa Cruz	
Target Population Size	200		200		200	
% of Females Lactating						
First-year	19%		19%		39%	
Other Adult	60%		60%		61%	
Pups per Adult Female	2.1		2.1		1.5	
Survivorship Values (%)	Pup	Adult	Pup	Adult	Pup	Adult
	70	70	70	70	70	74
	65	72	65	72	65	76
	60	74	60	74	60	78
	55	76	55	76	55	81
	50	78	50	78	50	83
	45	80	45	80	45	85
	40	83	40	83	40	88

A given percentage change in mean non-pup (adult) mortality results in a proportionally larger change in mean population growth rate compared to a similar change in pup mortality. In other words, behavior of thesefox models is more sensitive to adult mortality, which is relatively more important than pup mortality.

Target Population Sizes

Demographic modeling was used to evaluate how population size affected the ability of fox populations to persist over time, given both normal stochastic variation in vital rates, and the probability of catastrophic mortality factors (such as canine disease) sweeping through a population. Results from such modeling were then used to set target population sizes.

For this exercise, the previously used schedule of island-specific reproductive output was assumed, as well as typical pup survivorship values and attendant adult survivorship values that produced increasing populations.

For San Miguel (Tables 2, 3 and 4 in Appendix B), an initial population size of 100 adults produces probabilities of extinction (over a 50-year time period) of 12.8% with no catastrophic mortality agent, 22.4% with a mild catastrophic mortality agent, and 46.8% with a severe catastrophic mortality agent. If the initial population size is increased to 200, those extinction risks are 3.6%, 8.8%, and 37.2% respectively.

A distemper-like disease event can have a dramatic impact on the projected persistence of island fox populations, even if such an event occurs rather infrequently (Appendix B, Tables 3 and 4, Fig. 3). Under severe catastrophic mortality factors, even population sizes close to carrying capacity are not sufficient to buffer fox populations against the risk of extinction. This underscores the need for both active management to mitigate the effects of such mortality factors, and proactive management to reduce the chances of those factors acting on fox populations in the first place. Examples of the latter include field vaccinations for canine diseases, and assiduous efforts to keep domestic dogs off islands.

Given that population size does not buffer a population against catastrophic events, a reasonable target wild population size for San Miguel is one that reduces the chance of extinction over 50 years to less than 5%. The target population level is thus 200 individuals of breeding age. A population of 100 individuals has a 13% chance of extinction over 50 years, whereas a population of 200 individuals has a 4% chance of extinction over 50 years (assuming no catastrophic mortality agent).

For Santa Cruz, an initial population size of 100 yields a 6.4% chance of extinction, and an initial population size of 200 yields a 1.2% chance of extinction.

Vital rates and population trajectories were island-specific, and without such data from Santa Rosa Island it is impossible to model that population's target vital rates and population size. It would be most conservative to assume that Santa Rosa's rates are most like San Miguel's. Indeed, Santa Rosa's current fox population probably numbers no more than 30, with 22 of those in captivity. Therefore, the target population size and vital rates for San Miguel will also be used for Santa Rosa.

Table 3 summarizes target vital rates and population sizes for northern Channel Islands fox populations. For example, for San Miguel the target population size is 200, with proportion of females lactating being about 20% and 60% for juvenile and adult females, respectively. Number of pups per adult female should average approximately 2.1, and the minimal adult and juvenile survivorship values should be according to the schedule. These characteristics will result in a population that is increasing or stable.

Target Captive Breeding Schedule

Demographic modeling was used to analyze the supplementation, via captive breeding, required to recover fox populations to various levels (Roemer et al. 2000; see Appendix B). Not surprisingly, the greatest rate of population growth can be attained by supplementing the wild population with the maximum number of foxes annually. Assuming typical mortality and reproduction of released animals, supplementation of the San Miguel population (assumed to be currently zero) with 12 foxes annually brings the wild population to about 55 foxes five years after starting augmentation, to about 130 foxes within 10 years, and to 200 foxes within 15 years (see Fig. 4 in Appendix B). Thus, within 15 years of initiating supplementation, the San Miguel population can be brought to the target recovery level 200 individuals. A supplementation schedule of 12 foxes per year reduces the risk of extinction over a 50-year time period to about 6%, assuming no catastrophic mortality event (see Table 5 in Appendix B). If the augmentation rate can be increased (to greater than 12 foxes per year), then time to recovery will be less.

Average fecundity (defined as number of weaned pups) in the wild was approximately 2.0 pups per female on San Miguel and Santa Cruz (Coona et al. 1998, Roemer 1999). At this rate, six litters are required each year in order to produce 12 pups. Because litter size varies between one and four, and because not every pair will produce a litter, the number of pairs required to produce 12 pups is unknown, but may be between six and 18 (the latter assumes that one in three paired females bears a litter). The target captive breeding program size sufficient to annually produce 12 foxes is thus about 20 pairs.

General Strategy for Recovery

The general strategy for long-term recovery of the species is an extension of the emergency recovery actions implemented thus far. Long term recovery will be achieved by removing the human-caused mortality factors currently affecting island fox populations, and by increasing wild fox populations to population levels with vital rates that minimize the risk of extinction over time. Thus, predation by golden eagles must be eliminated or minimized on the northern Channel Islands. Island fox populations on San Miguel and Santa Rosa Islands must be augmented by captive breeding, and captive breeding may also be warranted for Santa Cruz Island.

It will require 5-10 years to build wild fox populations on San Miguel and Santa Rosa islands to population levels which minimize the risk of extinction over time. Even populations which approach carrying capacity (300-400 individuals on San Miguel) are not buffered against catastrophic mortality factors such as canine disease, and aggressive measures are required to prevent such mortality.

Island fox population sizes are inherently small, due to the limited range available to them on each island. Because stochastic variation in population vital rates alone can drive small populations of island foxes toward extinction (Roemer et al. 2000a; see Appendix B), wild populations must be closely monitored not only to gauge progress toward recovery criteria, but also to detect possible future declines. An adaptive management program must be implemented which prescribes management actions to be taken if predetermined threshold monitoring values are reached.

Additional research and monitoring needs to be conducted to gauge the status of the Santa Cruz Island fox population. Currently, distribution and abundance of island foxes on that island are not known well enough to decide whether captive breeding is warranted for the subspecies.

Finally, there are several large-scale ecological restoration actions which need to be completed in order to insure persistence of island foxes over time. The primary source of mortality for island foxes on the northern Channel Islands is predation by golden eagles. Golden eagle use of the northern Channel Islands is facilitated by the presence of feral pigs on Santa Cruz Island. Bald eagles, which bred historically on the northern Channel Islands, have been gone since the middle of the 20th century and are no longer a deterrent to golden eagles. The conversion of native shrubland to alien annual grassland has reduced cover available to island foxes from aerial predators. Thus for island foxes to persist over time, feral pigs need to be removed from Santa Cruz Island to reduce prey availability for golden eagles, bald eagles need to be restored to the northern Channel Islands, and native shrublands need to be restored.

Stepdown Narrative Outline of Recovery Actions

1.0 Coordinate and manage the island fox recovery program on the northern Channel Islands.

The island fox is not currently listed as endangered or threatened under the federal Endangered Species Act, nor is it likely to be in the near future. Thus, there is no official recovery team or plan promulgated by U.S. Fish and Wildlife Service. However, the complexity of issues impinging upon recovery, and the need for annual evaluation of recovery efforts, require a recovery team approach to island fox conservation on the northern Channel Islands. The team will comprise agency staff and staff from The Nature Conservancy, which manages natural resources on TNC lands on Santa Cruz Island under a cooperative agreement with the park.

At the species level, the species’ distribution over a range of jurisdictions, coupled with the number of factors affecting the species, underscore the need for a comprehensive recovery effort similar to those developed for listed species. Although individual subspecies are managed by different entities, each needs to be managed within the context of the species as a whole. Even though the development of such a species-wide recovery team and effort is beyond the scope of NPS management jurisdiction, NPS and affected agencies and landowners should meet regularly to exchange information on island fox status and recovery. In lieu of an official recovery team, the NPS encourages affected agencies and landowners to eventually come together via cooperative agreement or memorandum of agreement to coordinate island fox recovery efforts across administrative boundaries.

1.1 Assign coordinator.

To achieve coordination of recovery actions on park lands and to track and report progress toward recovery objectives, a coordinator needs to be assigned. The coordinator provides guidance, establishes annual objectives, develops funding proposals, organizes recovery team meetings and serves as primary contact for the program. Channel Islands National Park will provide a program coordinator for the duration of the recovery program on the northern Channel Islands.

1.2 Maintain island fox recovery team for the northern Channel Islands.

A northern Channel Islands island fox recovery team will be maintained for the duration of the recovery program. The recovery team will comprise individuals from federal agencies and The Nature Conservancy, and will be supported by a scientific advisory team of wildlife and conservation experts from academia and the conservation biology community.

The recovery team will be tasked with providing direction to the recovery effort. The scientific advisory team will provide periodic evaluation of recovery actions, and will consider issues as requested by the recovery team. The teams will meet annually or as needed. Portions of the teams will form working groups to address specific issues such as captive breeding, research and monitoring, and management of wild fox populations.

1.3 Develop a funding strategy.

Island fox recovery efforts will take as long as a decade, and will be as costly as some recovery programs for listed species. Obtaining the funding necessary to carry out recovery actions will be difficult, because the species is not listed and has little name recognition outside the region. Therefore, the National Park Service and its partner on Santa Cruz Island, the Nature Conservancy, must work together to develop a funding strategy that has the greatest opportunity to obtain funding from both public and private sources. Partnerships with national fundraising foundations may be necessary.

1.4 Participate in species-wide recovery efforts.

In order to ensure that island foxes on the northern Channel Islands are managed in the context of the entire species, NPS staff will attend periodic meetings of affected agencies and landowners, will coordinate recovery and monitoring activities to the extent possible. The NPS will also participate in development of a species-wide recovery plan, as well as a memorandum of agreement to effect such a coordinated effort.

2.0 Eliminate human-caused mortality factors.

Island foxes are extremely vulnerable to the two human-caused mortality factors currently impinging upon foxes, golden eagle predation in the northern Channel Islands, and canine distemper virus on Santa Catalina Island. Under the impact of these factors, island fox annual survival in the wild has fallen to 10% on some islands. These mortality sources must be eliminated or minimized if island foxes are to continue to persist.

2.1 Complete initial removal of golden eagles from northern Channel Islands.

Whereas there may be minimal levels of eagle presence and predation that may be acceptable, there is insufficient data and modeling to support this. Therefore the initial target for eagle management is to remove all existing eagles on the northern Channel Islands. Golden eagle removal will continue during winter and spring 2001 until all existing golden eagles are removed. Existing methodology will be used, in which eagles are trapped with bownets set over pig carcasses or live prey. If current methodology is not successful, alternative methods of removal, such as net-gunning from helicopter, will be used. If all live-capture methods fail, lethal removal methods may be used. Lethal removal methods would be used rarely, and only after obtaining a depredation permit from the U.S. Fish and Wildlife Service. Current indications are that seven eagles are still using Santa Cruz Island, and perhaps the other northern Channel Islands, at any one time.

2.2 Implement monitoring/response program for future golden eagles.

Until feral pigs are eliminated from Santa Cruz Island, regular monitoring will be conducted on Santa Cruz Island to detect golden eagles. Upon sighting an eagle or eagles, an eagle capture team will be sent to the island to capture and relocate the birds. Duration of the program and conditions for termination will be set.

3.0 Recover wild fox populations to viable levels.

On San Miguel and Santa Rosa Islands, fox populations are so low (less than 20 and 30 individuals, respectively), that extinction is a likely outcome if those populations are left unmanaged. Captive propagation is required to build the wild populations up to acceptable population levels and vital rates that minimize the risk of extinction over time.

Captive breeding and subsequent release of foxes into the wild comprise the bulk of the costs of recovery (Table 4). This is because captive foxes require full-time care, and released foxes require intense monitoring. Operationally, this is envisioned as one function for each island. At peak captive population and productivity (approximately 40 foxes in captivity on each island, with annual release of 12+ individuals into the wild), two biological technicians will be required to be on the island at all times. Since island personnel work one-week on and one-week off, eight biological technicians are needed at full capacity, plus one relief biological technician. We anticipate reaching this level of productivity as early as fiscal year 2004.

3.1 Set target population sizes and vi tal rates, and set target captive breeding program size and productivity.

For each population, target wild population sizes and vital rates must be set that minimize the risk of extinction over time. Demographic modeling of each population will accomplish this, using appropriate field data to construct each model. Once target demographic values are set for each population, then demographic modeling is used to set the size and duration of a captive breeding program that will achieve the target wild population size and vital rates within a reasonable time frame. Demographic modeling was conducted in November, 2000 (see Appendix B). Target population criteria and captive breeding productivity were set using the results of the demographic modeling (see Goals, Objectives and Criteria).

3.2 Establish and maintain captive breeding facilities on San Miguel and Santa Rosa Islands.

The NPS established captive breeding facilities on San Miguel and Santa Rosa Island in 1999 and 2000, respectively. There are 16 island foxes in the San Miguel facility and 22 foxes in the Santa Rosa facility. Foxes are housed singly or in pairs in welded-wire enclosures of approximately 500 square feet. For the 2000-20001 breeding season there are five pairs on San Miguel and nine on Santa Rosa. The facilities will be maintained as long as required to achieve recovery of wild populations on those islands.

3.2.1 Provide guidance for island fox captive breeding program.

Guidance for the island fox captive breeding program is provided by the captive breeding working group. The captive breeding working group provides guidance regarding fox care, facility design, breeding and reproduction, and release.

3.2.2 Expand facilities to meet target augmentation rates.

The target augmentation rate and corresponding facility size have been set using results from demographic modeling. Twenty to 25 pens are required on San Miguel and Santa Rosa Islands in order to produce 12 foxes annually. Current facility size is 11 pens on San Miguel and 14 pens on Santa Rosa. Facility size needs to be increased accordingly. This is particularly true on Santa Rosa, where potential pup production in spring 2000 could exceed the existing facility capacity. Doubling the current size would require additional staff to operate such an expanded facility.

3.2.3 Establish second site on each island to reduce disease risk.

Foxes in a captive breeding facility are in much closer proximity to each other than in the wild, and are thus vulnerable to a disease epidemic or other catastrophe. On San Miguel the risk is greater because all foxes, save one left in the wild, are in the captive breeding facility. To reduce the risk of canine disease or other catastrophe eliminating an entire captive population, an additional captive facility should be established on each island at sufficient distance from the first. Functionally, the facility expansions from 3.2.2 would comprise this second facility.

3.2.4 Establish studbook to track lineages, matings, and genetic resources.

A studbook is a recordkeeping system commonly used to track captive populations, and contains all the vital records of a captive population, including births, deaths and lineage. Data in the studbook can be used to help maintain the genetic and demographic integrity of a captive population. Studbooks are required elements of the American Zoo and Aquarium Associations' Species Survival Plans (SSP's). There is no SSP for the island fox, nor has the working group recommended establishing one. However, the team has recommended that a studbook be kept for the island fox captive breeding program. Studbook data are archived in program SPARKS, the Single Population Analysis and Recordkeeping System developed by the International Species Information System. Each studbook requires a "keeper" who is responsible for data entry and is trained in program SPARKS. Staff from The Living Desert Museum developed the initial studbook for the island fox captive breeding program, and keeper responsibilities may subsequently be transferred to the Santa Barbara Zoological Gardens. The park will provide the studbook keeper with relevant information to be entered into SPARKS, on an annual basis.

3.2.5 Develop veterinary protocols and enhance veterinary capabilities.

Formal veterinary protocols need to be developed for the captive breeding program, in order to insure that foxes receive regular, timely examinations and that injuries and illness are treated effectively. This is made difficult by the isolated nature of the islands and lack of veterinary staff on-island. Working group members are currently working to develop effective veterinary protocols.

3.2.6 Conduct safety trials for vaccines, antibiotics, and anthelminthics.

Until recently, island foxes have not been kept in captivity, and thus little is known about how they react to medical treatments and procedures commonly used on other canids. Island foxes have medical needs such as parasite loads and vulnerability to canine diseases that will require treatment. Trials need to be conducted with vaccines, antibiotics and anthelminthics prior to use on island foxes. Of necessity, trials have been conducted for canine distemper virus vaccine, and for some anthelminthics. Zoos and other institutions which now hold island foxes may be a good source of information on island fox reaction to medical treatments.

3.2.7 Conduct genetic analysis of captive fox populations.

Pairings are currently made utilizing information on area of capture and parentage, when known, but without the benefit of genetic data on parentage and relatedness. In fiscal year 2001 the park will fund genetic analysis of both captive fox populations using both mitochondrial DNA and microsatellite analysis of blood samples from captive foxes. Results will be used to determine relatedness and parentage of captive foxes, and will be available to make pairings for the 2001-2002 breeding season.

3.2.8 Investigate reproductive biology of island foxes.

Because island foxes have only recently been kept in captivity, next to nothing is known about their reproductive biology. The exact timing of breeding and the reproductive cycle, the gestation period, and typical litter sizes are all unknown. In order to maximize productivity from the captive breeding program, as well as to identify potential roadblocks to captive breeding, more information is needed regarding island fox reproduction. Because maintaining foxes in captivity represents an opportunity for research, the captive breeding program will cooperate with reproductive physiologists to obtain such information.

3.3 Supplement wild populations with captive-reared foxes.

In order for the captive breeding program to successfully augment wild fox populations, island foxes need to be released into the wild in a manner that maximizes their chances of survival, and facilitates their capability to reproduce in the wild. Explicit guidelines and island-specific plans need to be developed, foxes need to be released, and released foxes need to be monitored in order to insure adequate supplementation of wild fox populations.

3.3.1 Set conditions for captive releases.

The island fox recovery team needs to set specific criteria under which captive island foxes can be released to the wild. Factors which need to be considered include golden eagle and feral pig status, productivity of the captive breeding program, and available space in the captive facilities.

3.3.2 Develop captive release strategies for each island.

Prior to any release, a comprehensive release strategy and plan needs to be developed for each island. Such a plan will consider groups slated for release (family groups versus juveniles), area of the island, timing (season) of release, and methods of release (hard versus soft release).

3.3.3 Release captive foxes to wild and conduct post-release monitoring of reintroduced foxes.

Once conditions for captive release are met, and upon development of appropriate release strategies and plans, island foxes will be released into the wild on an annual basis, and released foxes will be monitored via radiotelemetry. Initially, each released fox will be radiocollared. Success of reintroduction depends on adequate survival of released individuals, and this can only be determined via radiotoelemetry. Annual capture of released foxes will allow evaluation of health and general condition, as well as parasite and disease prevalence.

3.4 Evaluate the need for captive breeding on Santa Cruz Island.

If the island fox population on Santa Cruz Island is critically low, and if high mortality and low fecundity persist in the wild population, then captive breeding will be required for that island, in order to safeguard foxes from mortality sources and build up the wild population to the point where risk of extinction is minimized. However, not enough is known currently about the Santa Cruz population to decide whether captive breeding is warranted. Additional field data is required, as well as demographic modeling, to make that decision.

3.4.1 Conduct field study on Santa Cruz Island to better estimate island fox population size and distribution.

Additional data regarding distribution, abundance, and survivorship of island foxes on Santa Cruz Island, in order to make a decision about captive breeding. In winter 2000-2001 the Institute for Wildlife Studies, under contract to The Nature Conservancy, began a year-long island fox investigation on Santa Cruz Island using transect-trapping and radiotelemetry to assess the status of the wild population on that island.

3.4.2 Conduct demographic modeling of Santa Cruz population with adjusted vital rates to determine if captive breeding is warranted or advised for that population.

Demographic modeling should be conducted for the Santa Cruz Island population using revised estimates for population size and survivorship from the field investigation. The demographic modeling results can then be used by the recovery team to recommend whether captive breeding is warranted or advised for Santa Cruz Island.

4.0 Implement adaptive management program.

Monitoring programs are effective only if appropriate management actions are tied to results of monitoring. For example, management actions should be taken if monitored population levels decline below a certain threshold level. Small populations such as those of the island fox are vulnerable to extinction from stochasticity in vital rates, as well as from human-caused or catastrophic sources of mortality. The small island fox populations need to be closely monitored, threshold values need to be determined for initiating management (such as return to captivity, or supplemental feeding, etc.), and the resources need to be in place to implement such management quickly and effectively.

4.1 Develop adaptive management program.

For each wild fox population, demographic modeling should be used to establish threshold values of vital rates which will trigger management action. A suite of appropriate management actions needs to be identified, with a schedule of implementation. Funding sources need to be identified for support of such actions.

4.2 Implement annual population monitoring of each subspecies/population.

Annual population monitoring needs to be conducted for each subspecies, in order to assess population health and identify “red flag” situations.

4.2.1 Conduct transect trapping and radiotelemetry monitoring.

The island fox populations in the northern Channel Islands are at extremely low population sizes, with significant mortality. The most appropriate monitoring scheme under such conditions is annual transect trapping combined with radiotelemetry of individual animals. Transect trapping allows wide coverage of an island, which is required under conditions of low density and large territory size. Trap success rate (number of foxes caught per number of available traps) is an index of population density, and reproductive success can be estimated by the ratio of pups to adult females. Radiotelemetry of individuals allows estimation of survivorship and identification of mortality factors.

5.0 Protect island foxes from canine diseases.

As canids which remain relatively isolated from domestic dogs and completely isolated from mainland carnivore species, island foxes are vulnerable to the introduction of canine diseases. Such concerns remained only a potential threat until 1999, when canine distemper virus decimated the island fox population on the eastern portion of Santa Catalina Island. The massive decline on that island occurred in less than a year, precipitating aggressive recovery actions for that subspecies, and underscoring the potential for canine diseases to drive epidemiologically naïve island fox populations toward extinction. Current disease impacts need to be mitigated, and proactive measures need to be taken to prevent future canine disease outbreaks in island fox populations.

5.1 Vaccinate wild foxes against canine distemper virus, if required.

As on Santa Catalina Island, outbreaks of canine distemper virus should be mitigated by vaccinating wild foxes against the virus. Unlike other canine diseases, distemper is extremely lethal and an outbreak rarely leaves behind resistant individuals in the population. Vaccination of wild foxes is a last-resort, fallback position which will be implemented only when there is failure of domestic dog management (see below) and a significant, imminent threat of distemper outbreak. The Santa Catalina Island Conservancy and the Institute for Wildlife Studies are currently vaccinating wild foxes on Santa Catalina Island, following successful vaccine trials with an experimental recombinant vaccine. Modified live vaccines should not be used on captive or wild island foxes.

5.2 Enforce no-dog policy on islands, and vaccinate working dogs.

The current prohibitions against bringing dogs ashore at Channel Islands National Park should be continue to be assiduously enforced. Dogs used on island projects such as feral pig removal, as well as dogs brought to the islands by permittees and holders of use and occupancy rights, should be vaccinated against canine distemper virus, canine parvovirus, and rabies.

6.0 Implement effective public outreach regarding conservation of island foxes.

A recovery program of this scope, magnitude and complexity requires broad public support. An effective strategy for public outreach must be developed, and should include a press/media plan, as well as elements of public education.

6.1 Develop media and educational plan.

The project coordinator will work with the park’s public information officer and interpretive staff to develop a media and education plan.

6.2 Educate the public about potential disease transmission from domestic dogs.

Key segments of the public may be unaware that island foxes are vulnerable to canine diseases, or that unvaccinated domestic dogs pose a threat to island foxes. Concerted education efforts which focus on these facts will help reduce the threat of future disease transmission. The boating public, including commercial and sport fisherman, will be targeted for such outreach efforts.

7.0 Implement other actions necessary for recovery.

Several major ecological restoration actions need to be taken to ensure long-term recovery of island fox populations. Feral pigs need to be removed from Santa Cruz Island, in order to reduce the ability of the island to support migrant, wintering, or breeding golden eagles. Alien annual grasslands on the northern Channel Islands need to be replaced with native shrub communities. Bald eagles need to be restored to the northern Channel Islands to provide a deterrent to golden eagles. Separate planning efforts are currently underway for these major actions, and so they will implemented independently of the actions in this plan.

7.1 Remove feral pigs from Santa Cruz Island.

Both the National Park Service and The Nature Conservancy recognize that removal of feral pigs from Santa Cruz Island is necessary in order to effect recovery of that island's ecological elements and processes. The NPS and TNC have developed a primary restoration plan for Santa Cruz Island, including the removal of pigs. The effort is expected to take as long as six years, and is scheduled to begin in fiscal year 2002 (which starts October 1, 2001). Removal of pigs from Santa Cruz Island will have long-term benefits for island foxes by removal of the primary prey species for golden eagles.

7.2 Reintroduce bald eagles to the northern Channel Islands.

Historically, bald eagles bred on the northern Channel Islands, but were extirpated from the islands by the mid-20th century due to persecution and the effects of organochlorine pesticides. Breeding bald eagles are highly territorial and would probably deter golden eagles from roosting, wintering, or breeding on the northern Channel Islands. The NPS has recognized the need to restore bald eagles to the islands' ecosystem but has heretofore lacked a funding source to accomplish reintroduction. However, a recent settlement in an environmental contaminant court case may provide such a funding source. Monies from the settlement of the Montrose chemical case should fund a feasibility study for bald eagle reintroduction. Under such a study, bald eagles could be released n the northern Channel Islands as early as summer, 2002.

7.3 Restore native vegetation communities of the northern Channel Islands

The park and The Nature Conservancy are currently working to restore native island vegetation communities. Tools used thus far include prescribed fire, removal of high-priority alien plant species, and the indirect benefits of exotic herbivore removal. Because native shrubs have been slow to colonize non-native annual grasslands, several research projects are underway to investigate the factors that are responsible. Due to the vast extent of alien annual grasslands, the slow natural recovery, and the relatively small scale of treatments, it may take decades to bring about significant recovery of island shrublands.

Part III Implementation Schedule and Cost Estimates

The implementation schedule is a guide for meeting the objectives identified in the recovery plan. This schedule identifies and prioritizes tasks, provides an estimated timetable for completion of tasks, identifies responsible parties, and estimates costs of recovery actions. These actions, when accomplished, will bring about recovery of island foxes.

Priorities are assigned as follows:

Priority 1: An action that must be taken to prevent extinction or prevent the species/subspecies from declining irreversibly in the foreseeable future.

Priority 2: An action that must be taken to prevent a significant decline in the species/subspecies' population or habitat quality, or some other significant negative impact short of extinction.

Priority 3: All other actions necessary to meet recovery or conservation objectives.

Definition of task duration and costs:

Continual: A task that, once begun, will be implemented on a routine basis.

Ongoing: A task that is currently being implemented and will continue until action is no longer necessary.

Project: A task that will be implemented on a one-time only basis, or until no longer required.

Responsible parties:

NPS	National Park Service
TNC	The Nature Conservancy
USN	U. S. Navy
TEAM	Island Fox Recovery Team
FWS	U. S. Fish and Wildlife Service
SBZG	Santa Barbara Zoological Gardens
SLZP	St. Louis Zoological Park
TLD	The Living Desert Wildlife and Botanical Park

Table 4. Implementation schedule and cost estimates for island fox recovery actions on the northern Channel Islands.

Implementation Schedule for Island Fox Recovery Plan															
					Cost Estimate (x $1,000)										
Task Priority	Task Number	Task Description	Task Duration	Resp. Parties	Total Costs	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3	1.0	Coordinate and manage the island fox recovery program for the northern Channel Islands.													
3	1.1	Assign coordinator.	Ongoing	NPS	700	70	70	70	70	70	70	70	70	70	70
3	1.2	Maintain island fox recovery team.	Ongoing	NPS	50	5	5	5	5	5	5	5	5	5	5
3	1.3	Develop a funding strategy.	Project	NPS											
3	1.4	Participate in species-wide recovery efforts.	Ongoing	NPS											
1	2.0	Eliminate human-caused mortality factors.													
1	2.1	Complete initial removal of golden eagles from northern Channel Islands.	Ongoing	NPS, TNC, FWS											
1	2.2	Implement monitoring/response program for future golden eagles.	Project	NPS, TNC	420	60	60	60	60	60	60	60			
1	3.0	Recover wild populations to viable levels.													
1	3.1	Set target population sizes and vital rates, and set target captive breeding program size and productivity.	Complet ed	NPS											
1	3.2	Establish and maintain captive breeding facilities on San Miguel and Santa Rosa Islands.	Ongoing	NPS	4566	257	367	457	467	477	487	497	508	519	530
1	3.2.1	Provide guidance for island fox captive breeding program.	Ongoing	Team											
1	3.2.2	Expand facilities to meet target augmentation rates.	Project	NPS	30	30									

Implementation Schedule for Island Fox Recovery Plan															
					Cost Estimate (x $1,000)										
Task Priority	Task Number	Task Description	Task Duration	Resp. Parties	Total Costs	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	3.2.3	Establish second site on each island to reduce disease risk.	Project	NPS											
3	3.2.4	Establish studbook to track lineages, matings, and genetic resources.	Ongoing	NPS, TLD, SBZG											
2	3.2.5	Develop veterinary protocols and enhance veterinary capabilities.	Ongoing	NPS	5	5									
2	3.2.7	Conduct genetic analysis of captive foxes.	Ongoing	NPS											
2	3.2.8	Investigate reproductive biology of island foxes.	Ongoing	SLZP											
1	3.3	Supplement wild populations with captive-reared foxes.	Project	NPS											
1	3.3.1	Set conditions for captive releases.	Project	Team											
1	3.3.2	Develop release strategies for islands.	Project	NPS, Team											
1	3.3.3	Release captive foxes to wild, conduct post-release monitoring of foxes.	Project	NPS											
2	3.4	Evaluate the need for captive breeding on Santa Cruz Island.	Project	Team											
2	3.4.1	Conduct field study on Santa Cruz Island to better estimate island fox population size and distribution.	Project	TNC											
2	3.4.2	Conduct demographic modeling of Santa Cruz population with adjusted vital rates to determine if captive breeding is warranted or advised for that population.	Project	NPS, TNC	5	5									
2	4.0	Implement adaptive management.	Continual												
2	4.1	Develop adaptive management program.	Project	NPS, Team	5	5									

Implementation Schedule for Island Fox Recovery Plan															
					Cost Estimate (x $1,000)										
Task Priority	Task Number	Task Description	Task Duration	Resp. Parties	Total Costs	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
2	4.2	Implement annual population monitoring of each subspecies/population.	Ongoing	NPS											
2	4.2.1	Conduct transect trapping and telemetry on the northern Channel Islands.	Continual	NPS, TNC											
1	5.0	Protect island foxes from canine diseases.													
1	5.1	Vaccinate wild foxes against canine distemper virus, if required.	Project	NPS											
1	5.2	Enforce no-dog policy on islands, and vaccinate working dogs.	Continual	NPS, TNC											
3	6.0	Implement effective public outreach regarding conservation of island foxes.	Continual	NPS											
3	6.1	Develop media and educational plan.	Project	NPS											
3	6.2	Educate the public about potential disease transmission from domestic dogs.	Continual	NPS	25	25									
1	7.0	Implement other actions necessary for recovery.													
1	7.1	Remove feral pigs from Santa Cruz Island.	Project	NPS, TNC	*										
1	7.2	Reintroduce bald eagles to the northern Channel Islands.	Project	NPS	*										
3	7.3	Restore native vegetation communities of the northern Channel Islands.	Project	NPS, TNC	*										
		TOTAL			5806	462	502	592	602	612	622	632	583	594	605

* Projects will be implemented independently of this plan.

Table 5. Unfunded needs (x $1,000) for island fox recovery actions, for which NPS will seek funding.

Task	Task Description	Total Cost	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1.2	Maintain island fox recovery team.	50	5	5	5	5	5	5	5	5	5	5
2.2	Implement monitoring/response program for future golden eagles.	240	30	30	30	30	30	30	30	30	0	0
3.2	Maintain captive breeding on San Miguel and Santa Rosa Islands.	4566	257	367	457	467	477	487	497	508	519	530
4.2.1	Conduct monitoring of released individuals.											
3.2.2	Expand facilities to meet target augmentation rates.	30	30									
3.2.5	Develop veterinary protocols and enhance veterinary capabilities.	5	5									
3.5.2	Conduct demographic modeling of Santa Cruz population.	5	5									
4.1	Develop adaptive management program.	5	5									
7.2	Educate the public about potential disease transmission from domestic dogs.	25	25									
	TOTAL	4926	362	402	492	502	512	522	532	543	524	535

Those actions, and their cost estimates, for which the National Park Service will seek funding are given in Table 5. Total cost to NPS is $ 4,926,000 over 10 years. Costs for fiscal year 2001 (October 1, 2000, to September 30, 2001) are not shown, because they are already funded.

The costs of captive breeding comprise the bulk of the costs the NPS will incur for the duration of the program.

Part IV Environmental Compliance

The primary actions proposed in this plan are categorically excluded from the National Environmental Policy Act compliance process, because they are actions with no potential, either individually or cumulatively, for significant environmental impact (Director's Order #12, Conservation Planning, Environmental Impact Analysis and Decisionmaking; NPS 2001b). Golden eagle removal from the northern Channel Islands, and captive breeding of island foxes with eventual reintroduction are categorically excluded under the following categorical exclusions from Director's Order #12 (NPS 2001b, section 3.4):

E. (2): Restoration of non-controversial native species into suitable habitats within their historic range.

E. (3): Removal of park resident individuals of non-threatened/endangered species or populations of pests and exotic species that pose an imminent danger to visitors or an immediate threat to park resources.

None of the exceptions to categorical exclusions (NPS 2001b, section 3.5) apply. Therefore, no environmental assessment or environmental impact statement will be prepared for the actions proposed in this recovery plan. The actions fall into the group of categorical exclusions for which a record is required (NPS 2001b, section 3.4) Categorical exclusion forms will be filled out and kept on file at Channel Islands National Park Headquarters, Ventura, California.

Consultation and Coordination

This plan was prepared by the National Park Service in consultation with the following individuals and agencies. Members of the ad hoc island fox working group are indicated by an asterisk.

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Part VI Appendices

Appendix A Findings and Recommendations from the Island Fox Working Group, April, 1999

FINDINGS AND RECOMMENDATIONS FROM THE ISLAND FOX WORKING GROUP

Convened in Ventura, California

April 21-22, 1999

Meeting Participants:

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FINDINGS:

Island foxes are declining rapidly toward extinction on the three northern islands.

At least one identified mortality source, predation by golden eagles, has been confirmed. Golden eagles continue to occur on the islands. Loss of historic bald eagle populations from past human impacts (e.g. pesticides), a simplified island habitat from human disturbance, and increased exotic prey availability (e.g. pigs) have unnaturally increased the prevalence of golden eagles on the islands.

Other mortality factors are under investigation and may include disease and/parasites. These potential factors pose an ongoing risk to island foxes.

On San Miguel and Santa Rosa Islands, fox populations are so diminished that continued persistence in the wild is unlikely. On Santa Cruz Island, the population decline is serious but does not appear to be at the crisis level found on the other northern islands.

RECOMMENDATIONS:

1) Initiate immediate rescue/capture efforts of island foxes on San Miguel and Santa Rosa Islands. Captured animals will be held in on-island sanctuaries (pens). All captured animals will receive a comprehensive health evaluation by qualified wildlife veterinarians. Animals will be carefully monitored and evaluated while in captivity and will receive appropriate professional care at all times. The rescue/capture effort serves two purposes:

  a) to provide sanctuary for the few animals that continue to exist on the islands;
  b) to acquire animals necessary for a more detailed captive breeding program to be developed as part of a comprehensive recovery plan for the island fox.

Rescue/capture efforts will begin immediately. All non-reproductive animals will be relocated to the on-island sanctuary. Reproductive individuals will be radio-marked and recaptured after denning in mid-June.

2) Initiate immediate live-capture and relocation of golden eagles from the northern islands. Golden eagles will be humanely captured, radio-marked, and relocated to appropriate distant sites with suitable habitat.

3) Develop a comprehensive species recovery plan to address ultimate recovery goals and objectives. This will include developing specific plans and detailed protocols for animals in the sanctuary and for a captive breeding program to recovery the species. In addition, the recovery plan will include continued research and monitoring of island fox populations on Santa Cruz Island to elucidate factors causing decline.

4) Provide all appropriate data and information about island fox biology and conservation to the U.S. Fish and Wildlife Service to initiate evaluation of this species for listing under the Endangered Species Act.

5) Aggressively move forward with the reintroduction of bald eagles on the northern islands. This recommendation is based on findings that bald eagles can deter golden eagles from establishing, that bald eagles pose a negligible threat to island foxes, and that bald eagles were a historic component of the island fauna.

Appendix B Results from Demographic Modeling Workshop

Population Viability Assessment for Selected Channel Island Fox Wild Populations

Philip S. Miller, Gary W. Roemer, Jeff Laake, Chris Wilcox, and Timothy J. Coonan

Introduction

Population viability analysis (PVA) can be an extremely useful tool for assessing current and future risk of wildlife population decline and extinction. In addition, the need for and consequences of alternative management strategies can be modeled to suggest which practices may be the most effective in conserving the Channel Island fox (*Urocyon littoralis*) in its wild habitat. *VORTEX*, a simulation software package written for population viability analysis, was used here as a mechanism to study the interaction of a number of fox life history and population parameters treated stochastically, to explore which demographic parameters may be the most sensitive to alternative management practices, and to test the effects of selected island-specific management scenarios.

The *VORTEX* package is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wild populations. *VORTEX* models population dynamics as discrete sequential events (e.g., births, deaths, sex ratios among offspring, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modeled as constants or random variables that follow specified distributions. The package simulates a population by stepping through the series of events that describe the typical life cycles of sexually reproducing, diploid organisms.

VORTEX is not intended to give absolute answers, since it is projecting stochastically the interactions of the many parameters used as input to the model and because of the random processes involved in nature. Interpretation of the output depends upon our knowledge of the biology of the Channel Island fox, the environmental conditions affecting the species, and possible future changes in these conditions. For a more detailed explanation of *VORTEX* and its use in population viability analysis, refer to Miller and Lacy (1999) and Lacy (2000).

Specifically, we were interested in addressing the following tasks:

- Use revised demographic data, subject to stringent statistical analysis, to construct specific simulation models for fox populations on San Clemente, San Miguel, and Santa Cruz Islands;
- Test these models retrospectively against observations derived from field data beginning in 1993;
- Determine minimum levels of age-specific survival required for positive growth among island populations;
- Using minimum survival estimates, estimate risk of population extinction as a function of population size in the presence of stochastic probability infrequent disease (i.e., distemper virus);
- Evaluate a suite of alternative captive breeding strategies for their efficacy in minimizing population extinction risk.

Input Parameters for Stochastic Population Viability Simulations

The datasets used to parameterize our *VORTEX* population viability model come primarily from the trapping and telemetry work of Gary Roemer and Dave Garcelon on Santa Cruz Island (SCR) and San Clemente Island (SCL) and Tim Coonan on San Miguel Island (SMI). These studies provide reasonably complete pictures of more short-term demographic processes operating on fox populations: data from SCL begin in 1988 while those on SMI and SCR begin in 1993. As our ultimate goal is to develop similar models specific to each island, we may depend heavily on these datasets for parameterization and must recognize that we may be neglecting to include some of the specific processes operating on different islands.

In addition, it is important here to distinguish the traditional practice of identifying individual foxes by age class (usually from tooth-wear patterns) from that of assigning a numerical age to each individual. This conversion is necessary, as *VORTEX* is an individual-based, age-structured model. Based on field experience and best estimates, the translation is as follows:

Age Class	Age in years
1	1
2	2 – 3
3	4 – 5
4	> 5

For specific details on the statistical analyses of mark-recapture data used to derive the vital rates used in these models, refer to the appropriate sections of this report.

<u>Breeding System</u>: Monogamous. Under this assumption, an adult male will breed only once per year; as a result, a restriction in the number of adult males in a small population may limit the extent of breeding. Furthermore, the model allows a given male to breed with a different female the following year; in other words, long-term monogamy is not the norm.

<u>Age of First Reproduction</u>: Because of the nature of the field data available to us, we defined “reproduction” as the production of pups that are successfully weaned. Roemer’s data on reproduction is based specifically on direct observation of lactating females. In addition, *VORTEX* precisely defines reproduction as the time at which offspring are born, not simply the age of sexual maturity. The program uses the mean age rather than the earliest recorded age of offspring production. While the majority of individuals do not begin producing pups until they are 2 years old, some 1-year-olds have been observed to breed on both SCR and SMI. Consequently, we assumed that reproduction could begin at one year of age.

<u>Age of Reproductive Senescence</u>: *VORTEX* initially assumes that animals can reproduce (at the normal rate) throughout their adult life. Observations made in the field suggest that foxes may live and breed up to about 9 years of age. However, older individuals will have considerably more difficulty establishing and/or maintaining territories, thereby leading to a reduced reproductive output. This feature can be included in the specification of reproductive success.

<u>Offspring Production</u>: Based on field observations of radio-collared individuals, and mark-recapture analysis of grid-trapping methods, researchers conclude that reproductive success

(defined here as the percentage of adult females successful weaning a set of pups) varies with age. Specifically, we developed the following age-specific values for each of the three islands studied here:

			Island	
Age Class	Age in Years	San Clemente	San Miguel	Santa Cruz
1	1	43.8	18.9	38.6
2	2 – 3	73.2	60.0	61.3
3	4 – 5	97.5	60.0	61.3
4	> 5	75.0	60.0	61.3

At this time, we are not including any form of density dependence in reproductive success. Future modeling efforts, using *VORTEX* or any other package, could investigate the impact such dependence could have on population growth and associated risk of decline or extinction.

Additional data analysis gave us the island-specific distribution of the number of weaned pups produced per successful adult female:

		Island	
Number of Pups	San Clemente	San Miguel	Santa Cruz
1	78.8	32.4	55.8
2	21.2	41.2	35.6
3		14.7	8.6
4		11.7	
Mean	1.21	2.06	1.53

Data across islands suggest a sex ratio (percent males) among newly weaned pups of 50%.

Annual environmental variation in female reproduction is modeled in *VORTEX* by specifying a standard deviation (SD) for the proportion of adult females that successfully wean pups within a given year. Based on analysis of trap data for each island, we assumed a standard deviation in this parameter of 17%.

<u>Male Breeding Pool</u>: In many species, some adult males may be socially restricted from breeding despite being physiologically capable. This can be modeled in *VORTEX* by specifying a portion of the total pool of adult males that may be considered "available" for breeding each year. We assumed that each adult male is equally capable of establishing a territory and, therefore, is equally capable of breeding in a given year. This is not to say, however, that every male is actually successful in that same year. Stochastic variation in the number of females that breed, as well as the annual fluctuations in the total number of adults, may lead to some males being unsuccessful.

<u>Mortality</u>: Data on age-specific mortality are based largely on radio-telemetry observations of collared individuals. For simplicity, we categorized individuals as either pups (weaned to age 1) or non-pups (age 1 and above). This simplification was justified by the observation that exploratory models with specific mortality levels given for 3-year old individuals did not show a

significant difference from these simplified models in overall performance. It is important to remember that our estimates of pup mortality are from the time of weaning until their first birthday, as neonatal mortality is already factored into our estimates of female reproductive success (see above). Presumably, these data were taken at a time before significant population declines occurred through the actions of new predators, diseases, etc. Note that these datasets do not suggest differences in mortality rates between males and females.

For those models specifically designed to simulate recent past trends in island-specific population trajectories, we attempted to define mortality rates that most closely matched field data and past population performance. In general, this means that we had to define mortality rates for San Miguel and Santa Cruz that increased rapidly over time once significant mortality factors (e.g., golden eagles) began to emerge during and/or after 1993. The time-specific mortality rates are given below, where Y designates the year of the simulation.

	Island-Specific Mortality (%)		
Age Class	San Clemente	San Miguel	Santa Cruz
Pup	47.0 (8.0)	15.0+16.0*Y (6.5)	46.0+10.2*Y (11.0)
Non-Pup	28.0 (5.0)	7.0+16.0*Y (4.5)	33.5+5.0*Y (3.0)

For those models designed to investigate future population dynamics as a function of mortality, we simplified the mortality rates by removing the time function. Pup mortality was set to range between 30% and 60% by increments of 5%, while non-pup mortality ranged from 10% to 30% by increments of 2%.

Inbreeding Depression: *VORTEX* includes the ability to model the detrimental effects of inbreeding through reduced survival of pups through their first year. Initial attempts to model the populations of foxes across the Channel Islands focus here on the demographic characteristics of the population and, as such, did not incorporate inbreeding depression in the models described here. Further modeling efforts may benefit from an inclusion of this factor, especially as the fox populations have declined significantly below recent levels. Some argument could be made, however, against the inclusion of inbreeding depression as a component of the models as molecular data collected by Bob Wayne suggest very low levels of genetic diversity within island populations.

Catastrophes: Catastrophes are singular environmental events that are outside the bounds of normal environmental variation affecting reproduction and/or survival. Natural catastrophes can be tornadoes, floods, droughts, disease, or similar events. These events are modeled in *VORTEX* by assigning an annual probability of occurrence and a pair of severity factors describing their impact on mortality (across all age-sex classes) and the proportion of females successfully breeding in a given year. These factors range from 0.0 (maximum or absolute effect) to 1.0 (no effect), and are imposed during the single year of the catastrophe, after which time the demographic rates rebound to their baseline values.

Selected risk analysis models included a specific catastrophic event designed to simulate a disease similar to the canine distemper epidemic that recently devastated the Santa Catalina fox population. While historic data on the frequency of such an occurrence is scant indeed, we made the initial (and likely conservative) assumption that a distemper epidemic would occur on an island, on average, once in a 50-year period (equivalent to a 2% annual probability of occurrence). In order to assess the impact of such an epidemic, alternative models were developed in which the impact of the event was either considered to be mild (severity factor = 0.5, akin to a 50% increase in mortality during the event) or severe (severity factor = 0.1, akin to a 90% increase in mortality during the event).

Initial Population Size: Retrospective models initialized as of 1993 included population size estimates consistent with that time period: San Clemente, 680; San Miguel, 400; Santa Cruz, 1000. Subsequent models designed to assess the impact of population size on extinction risk included the following set of initial sizes for each island population:
San Clemente: 680, 600, 500, 400, 300, 200, 100, 50, 25
San Miguel: 15, 20, 40, 60, 80, 100, 200, 300, 400
Santa Cruz: 80, 100, 200, 300, 400, 500, 600, 800, 1000

VORTEX distributes the specified initial population among age-sex classes according to a stable age distribution that is characteristic of the mortality and reproductive schedule described previously.

Carrying Capacity: The carrying capacity, K, for a given habitat patch defines an upper limit for the population size, above which additional mortality is imposed randomly across all age classes in order to return the population to the value set for K.

In general, estimates of the carrying capacity of a given habitat are notoriously difficult to obtain. Indirect evidence for each island suggests that, before populations began to decline precipitously, total population size was likely to be near but slightly below carrying capacity. Consequently, we set K for San Clemente to be 1000, for San Miguel to be 500, and for Santa Cruz to be 1200.

Iterations and Years of Projection: All scenarios were simulated 250 times, with population projections extending to 50 years. All simulations were conducted using *VORTEX* version 8.41 (June 2000).

Results from Simulation Modeling

I. Retrospective Population Analysis

A set of three "baseline" models were developed in an attempt to mimic the actual population trajectories from 1993 to 2000 for San Clemente, San Miguel and Santa Cruz Island fox populations. This was done in order, through confirmation of expected model performance, to lend additional credibility to subsequent simulation-based investigations of island population risk.

The size trajectories for each of the three simulated island populations are given in Figure 1. Immediately apparent from the trajectories is the extremely rapid decline on San Miguel and Santa Cruz: estimates of population growth rate calculated directly from the simulations suggest rates of decline approaching 70% annually. Extinction occurs within ten years because of this rapid rate of decline. The 9% annual rate of decline seen in the simulated San Clemente population appears to be higher than the estimated 2-3% rate estimated from recent census counts, but these census counts focus solely on adults and could be prone to some error.

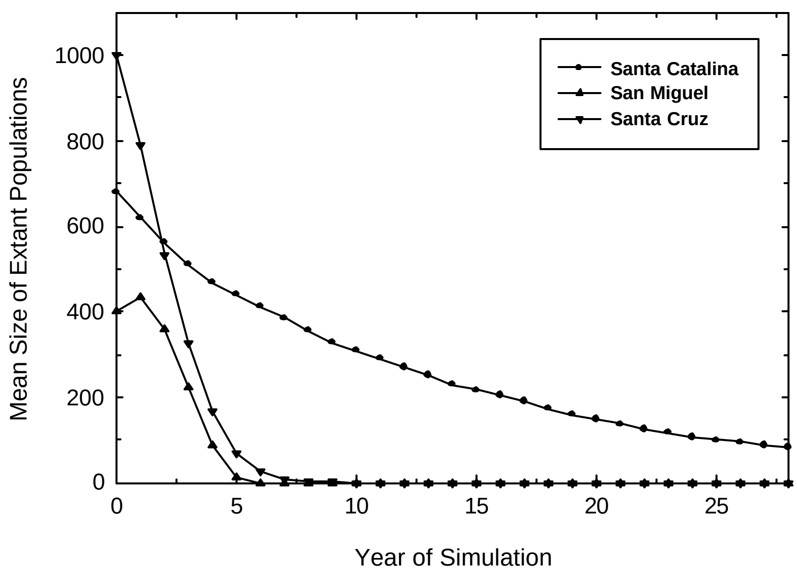


Figure 1. Size trajectories for simulated fox populations on selected Channel Islands. The retrospective models are an attempt to mimic actual population trends first observed after 1993 (shown here as Year 0 on the X-axis).

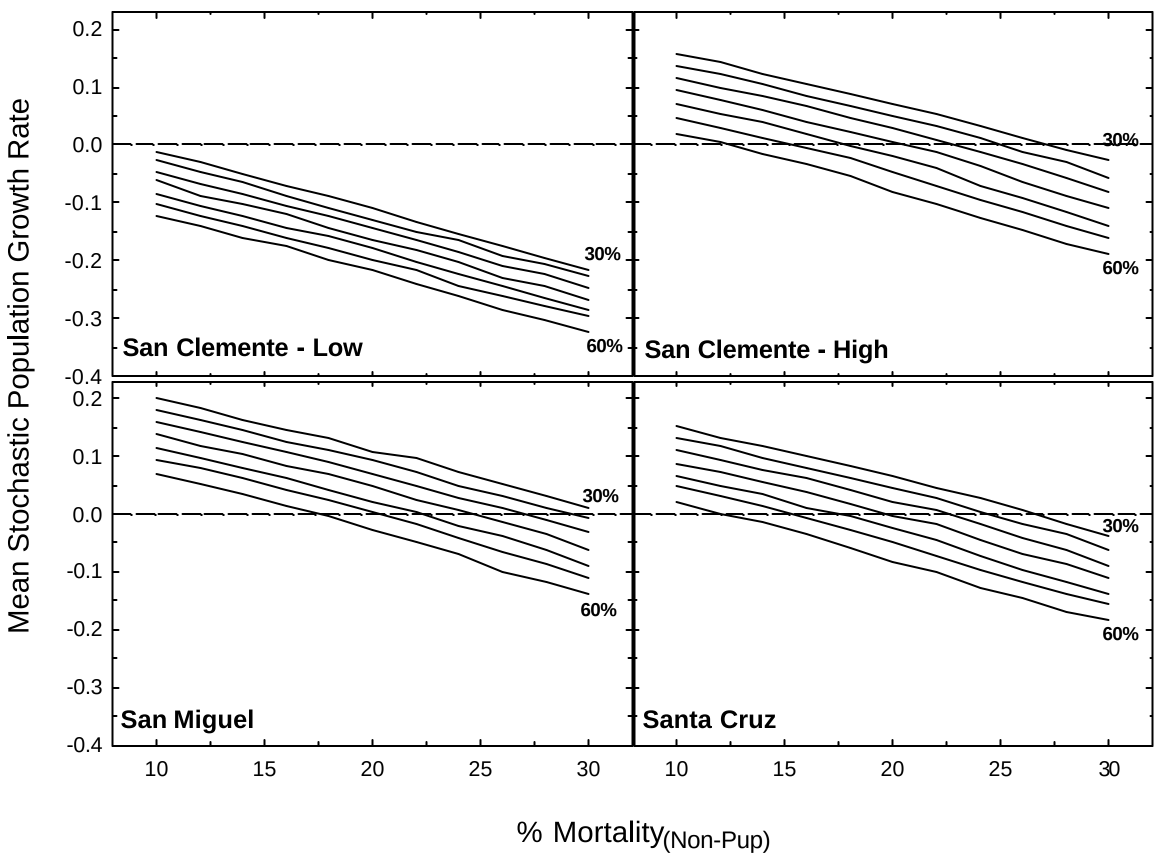
All in all, these test models suggest that those parameters chosen as best-estimate “baseline” values for reproductive success and survival generate reasonable simulations of Channel Island fox population demography. Consequently, we feel confident that the results generated from subsequent models can and will lead to meaningful insights into Channel Island fox population dynamics and alternative management options designed to minimize the risk of island-wide extinction.

II. Mortality Analysis

Once the retrospective analysis was successfully completed, we set out to develop a set of models with the goal of identifying minimum levels of survival necessary to prevent fox population decline. This was done in order to provide a better understanding of fox population dynamics, to define a broad set of minimal conditions necessary to increase the chances of population persistence, and to gain additional insight into the magnitude of the current detrimental impact of major mortality factors, such as feral pigs (perhaps indirectly) and golden eagles (directly). It is important to note that this particular analysis does not include certain stochastic elements of population dynamics, most notably the addition of catastrophic events. This was intentional, as we were focused in this task on developing estimates of annual mortality that were consistent with populations that were remaining stable in size or perhaps slightly increasing. This can provide a simple benchmark to which wild population management and associated field monitoring efforts can be directed.

A total of 308 individual models (also known as scenarios) were constructed that provided all possible combinations of four levels of reproductive success, seven levels of pup mortality, and eleven levels of non-pup mortality. Three of the four levels of reproductive success corresponded directly to the three island-specific estimates discussed previously (see paragraphs titled "Offspring Production" in the previous section). A fourth category was derived from the San Clemente reproductive schedule by reducing those age-specific baseline percentages of successfully breeding adult females by 50%. This was done in order to more effectively address the relationship between reproductive success and age-specific mortality required for population growth.

Figure 2. Channel Island fox population mortality analysis. Plots give average population growth rate (*r*) as a function of annual mortality rate of non-pups (animals aged 1 year and older) with individual lines corresponding to different levels of pup mortality. Four panels correspond to variable levels of adult female reproductive success (see text for additional details on the determination of success).



The results of this analysis are shown in Figure 2 and Table 1. With the exception of the low-fecundity San Clemente scenarios, it is clear that a number of combinations of pup and non-pup mortality can result in a population that is not expected to decline over time (i.e., $r > 0.0$). Inspection of these graphs lead to the following conclusions:

- As the mortality of pups increases from 30% to 60%, the maximum level of mortality consistent with a positive growth rate decreases. In other words, greater pup mortality results in less flexibility in allowable levels of non-pup mortality.

Table 1. Interaction of female fecundity (% adult females breeding annually) and pup mortality on the level of non-pup mortality required to produce a stochastic population growth rate expected to be approximately ≥ 0.0

Island / Fecundity	Pup Mortality	Critical Non-Pup Mortality
San Clemente / Low	30	<10
	35	<10
	40	<10
	45	<10
	50	<<10
	55	<<10
	60	<<10
San Clemente / High	30	28
	35	25
	40	22
	45	20
	50	17
	55	15
	60	12
San Miguel	30	30
	35	28
	40	26
	45	24
	50	22
	55	20
	60	17
Santa Cruz	30	26
	35	24
	40	22
	45	19
	50	17
	55	15
	60	12

- Higher levels of reproductive success allow for higher levels of acceptable mortality. This relationship is most clearly demonstrated when comparing the low-fecundity San Clemente scenarios (upper left panel) and the San Miguel scenarios (lower left panel).
- Obviously, the low levels of reproductive success that define the low-fecundity San Clemente scenarios are unrealistic from the standpoint of realistically characterizing a wild fox population on that island; only very low mortality rates give a mean positive population growth rate.
- As was the case with previous attempts at modeling wild Channel Island fox population dynamics, inspection of these graphs demonstrates that a given percentage change in non-

pup (adult) mortality results in a proportionally larger change in mean population growth rate compared to a change in up mortality of the same magnitude. In other words, the results of our fox population models are more sensitive to non-pup (adult) mortality.

In order to develop additional risk assessment models, it was necessary to choose a specific set of mortality values that would carry through the remainder of the analysis. Many of the wild fox populations appear to have pup mortalities near 45% (at least during the period of time immediately preceding the recent population crashes). Consequently, this value was chosen as our mortality "anchor point" around which estimates were made for each island of the level of non-pup mortality required to achieve a rate of population growth at or just above 0.0. For San Clemente, non-pup mortality was therefore set at 20%, San Miguel mortality at 24%, and Santa Cruz mortality at 19%.

III. Risk Assessment I: Population Size and Disease

By developing an island-specific mortality schedule that leads to an average annual population growth rate at or just above 0.0, we can simulate a situation in which major threats to the population have been ameliorated to a (perhaps minimally) desirable level. However, achieving this lower level of mortality does not eliminate the risk of population extinction. Stochastic variation in annual vital rates, in concert with infrequent but severe catastrophic events, can put a population at risk of extinction despite a long-term growth rate that is expected to result in a population increase. Our next task was to develop more realistic risk assessment models for each of our three Channel Island fox populations. We did this by incorporating infrequent but potentially devastating disease events into our original baseline models, and chose levels of age-specific mortality in the manner discussed above. In addition, we ran each type of model with a range of initial population sizes as that we could begin to see a picture of the size of a given island fox population that would be at least partially immune from the deleterious impacts of random variation in demographic rates brought about through demographic and environmental stochasticity.

For each island-specific set of scenarios that did not include a disease event, the risk of extinction over the 50-year simulation period was less than about 1% for populations greater than 200 individuals (Figure 3, Table 2). In addition, these same scenarios showed growth rates that were easily within the range expected from the mortality schedules used as input (r_s = 0.000 to 0.010). However, when the initial population size dropped below 200, the risk of extinction rose dramatically for the San Miguel and San Clemente populations, rising to as high as 73.6% over 50 years. As a result of this high risk, overall mean population growth rates dropped below 0.0 as stochastic factors acted to destabilize population dynamics The Santa Cruz population retained positive population growth rates, but the risk of population extinction over the period of the simulations increased to more than 6%. Taken together, these results graphically demonstrate the impact that year-to-year variation in vital rates, resulting primarily from environmental stochasticity, can have on population stability (or the lack thereof). This type of variation can act to generate a significant risk of population extinction, even when the population is expected to grow in size over the long-term based on mean levels of fecundity and mortality.

Table 2. Risk assessment for simulated Channel Island fox populations as influenced by initial population size. In each scenario, pup mortality is taken to be 45% and non-pup mortality is chosen from the value listed in Table 1 that gives a mean growth rate of approximately 0.0. Output listed includes the stochastic growth rate (with standard deviation), the probability of population extinction within a 50-year time period, and mean (standard deviation) size of populations remaining extant over 50 years.

Island	N_0	r_s (SD)	P(E)	N_{50} (SD)
San Clemente	680	0.003 (0.110)	0.000	635.8 (258.1)
	600	0.004 (0.110)	0.000	629.2 (250.4)
	500	0.003 (0.110)	0.000	573.9 (282.8)
	400	0.004 (0.111)	0.000	523.5 (285.8)
	300	0.003 (0.112)	0.000	434.8 (284.3)
	200	0.003 (0.117)	0.004	328.4 (265.5)
	100	-0.007 (0.133)	0.084	151.3 (159.3)
	50	-0.016 (0.154)	0.252	73.80 (84.3)
	25	-0.025 (0.181)	0.556	49.20 (54.3)
San Miguel	15	-0.025 (0.259)	0.736	79.90 (83.3)
	20	-0.016 (0.245)	0.560	82.10 (94.7)
	40	-0.012 (0.224)	0.364	124.4 (129.7)
	60	-0.004 (0.210)	0.196	148.8 (139.2)
	80	-0.005 (0.208)	0.132	152.5 (144.4)
	100	-0.002 (0.197)	0.128	179.8 (143.7)
	200	0.000 (0.188)	0.036	232.2 (153.8)
	300	0.003 (0.183)	0.004	265.4 (153.3)
	400	0.005 (0.183)	0.004	288.1 (151.6)
Santa Cruz	80	0.001 (0.158)	0.060	174.7 (177.4)
	100	0.004 (0.155)	0.064	255.3 (276.7)
	200	0.006 (0.146)	0.012	408.0 (342.2)
	300	0.006 (0.144)	0.016	524.0 (355.5)
	400	0.010 (0.141)	0.000	629.4 (367.9)
	500	0.008 (0.140)	0.000	664.9 (352.5)
	600	0.008 (0.141)	0.000	702.9 (358.0)
	800	0.010 (0.139)	0.000	770.2 (309.5)
	1000	0.008 (0.141)	0.000	733.1 (303.0)

Figure 3 and Tables 3 and 4 show the dramatic impact that a distemper-like disease event can have on Channel Island fox populations – even when those events are assumed to occur rather infrequently. The action of what we called a "mild" event one in which age-specific survival was reduced by 50% – served to effectively double the risk of extinction at intermediate population sizes (e.g., 50 – 100 individuals). The severe event, in which age-specific survival was reduced to just 10% of its baseline value, imposes a major increase in extinction risk. More importantly, this increased risk occurs at al population sizes. Indeed, the impact of this type of event is most noticeable at the largest population sizes: where disease-free scenarios resulted in positive population growth and no risk of extinction, severe disease scenarios produced extinction risk profiles approaching 30% over 50 years for populations as large as 680 individuals. Moreover, population growth rates for all disease scenarios were negative. This type of analysis dramatically demonstrates the considerable impact that a severe disease event can have on long-term population dynamics. It is extremely important to remember that this type of event modeled here is not based on pure conjecture and guesswork – the recent distemper outbreak on Santa Catalina reduced the island fox population by 80 – 90% in just 1 – 2 years. Clearly, effective management of Channel Island fox populations must grapple with this vital issue of disease transmission across species boundaries, and the potential for a marked increase in this transmission risk as humans increase their use of the Island landscape.

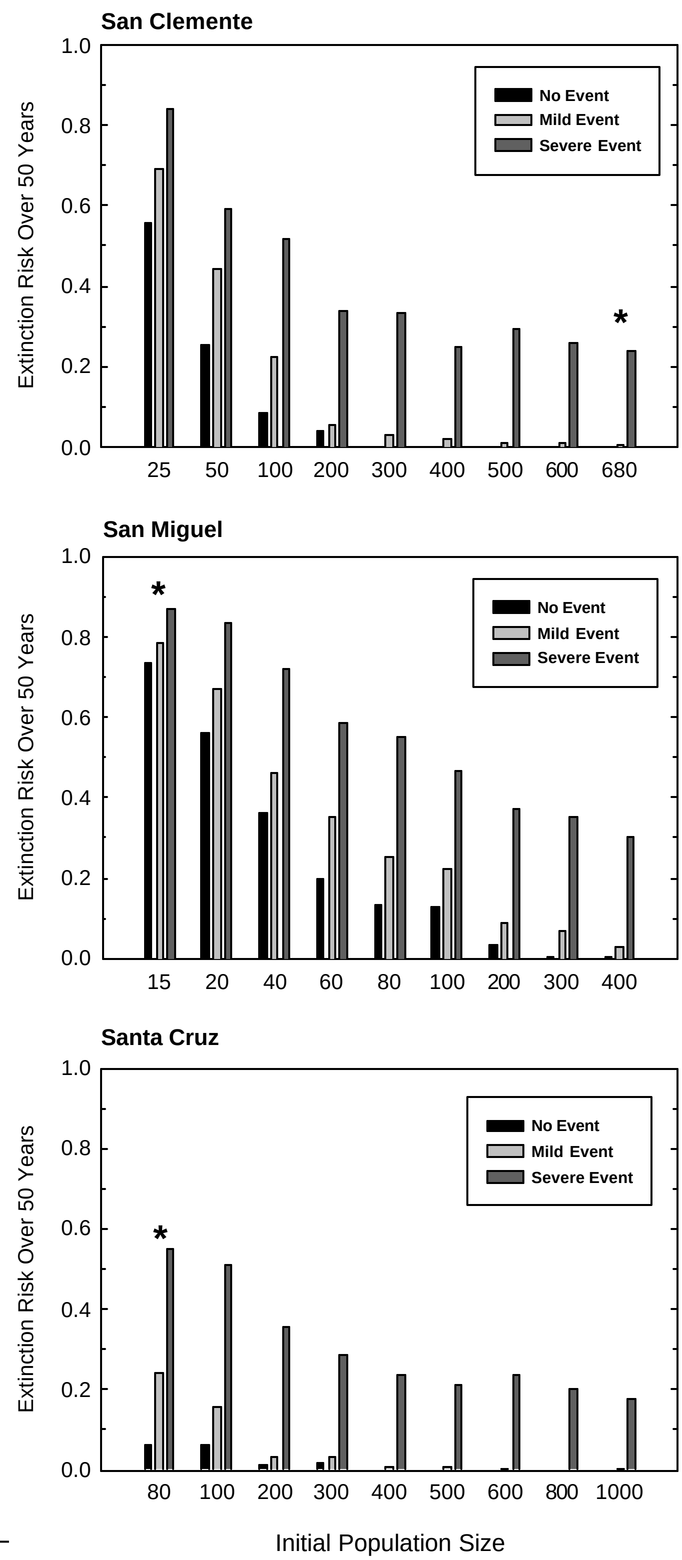
Table 3. Risk assessment for simulated Channel Island fox populations as influenced by initial population size and the inclusion of a distemper-like disease event that occurs on average once every 50 years and results in 50% additional mortality. In each scenario, pup mortality is taken to be 45% and non-pup mortality is chosen from the value listed in Table 1 that gives a mean growth rate of approximately 0.0. Output listed includes the stochastic growth rate (with standard deviation), the probability of population extinction within a 50-year time period, and mean (standard deviation) size of populations remaining extant over 50 years.

Island	N_0	r_s (SD)	P(E)	N_{50} (SD)
San Clemente	680	-0.009 (0.144)	0.004	458.1 (291.6)
	600	-0.010 (0.151)	0.008	426.6 (291.0)
	500	-0.010 (0.148)	0.008	391.5 (278.2)
	400	-0.013 (0.150)	0.020	340.1 (285.9)
	300	-0.010 (0.155)	0.028	301.6 (262.2)
	200	-0.014 (0.156)	0.056	207.7 (209.2)
	100	-0.025 (0.177)	0.224	107.5 (127.7)
	50	-0.028 (0.190)	0.444	75.2 (87.5)
	25	-0.039 (0.210)	0.692	38.5 (63.5)
San Miguel	15	-0.037 (0.272)	0.784	51.0 (80.8)
	20	-0.026 (0.267)	0.672	76.3 (89.2)
	40	-0.022 (0.244)	0.460	104.3 (126.7)
	60	-0.021 (0.242)	0.352	102.8 (116.3)
	80	-0.017 (0.228)	0.252	129.9 (125.9)
	100	-0.019 (0.232)	0.224	134.0 (137.2)
	200	-0.010 (0.213)	0.088	204.8 (162.9)
	300	-0.012 (0.214)	0.068	200.3 (156.3)
	400	-0.012 (0.210)	0.028	203.3 (153.2)
Santa Cruz	80	-0.022 (0.200)	0.244	131.0 (189.4)
	100	-0.016 (0.194)	0.156	164.7 (220.2)
	200	-0.009 (0.180)	0.032	262.2 (281.0)
	300	-0.006 (0.174)	0.032	398.2 (355.4)
	400	-0.006 (0.175)	0.008	418.9 (351.4)
	500	-0.008 (0.175)	0.008	458.7 (355.0)
	600	-0.009 (0.175)	0.004	473.2 (369.4)
	800	-0.008 (0.172)	0.000	511.1 (369.9)
	1000	-0.007 (0.173)	0.004	567.6 (368.5)

Table 4. Risk assessment for simulated Channel Island fox populations as influenced by initial population size and the inclusion of a distemper-like disease event that occurs on average once every 50 years and results in 90% additional mortality. In each scenario, pup mortality is taken to be 45% and non-pup mortality is chosen from the value listed in Table 1 that gives a mean growth rate of approximately 0.0. Output listed includes the stochastic growth rate (with standard deviation), the probability of population extinction within a 50-year time period, and mean (standard deviation) size of populations remaining extant over 50 years.

Island	N_0	r_s (SD)	P(E)	N_{50} (SD)
San Clemente	680	-0.046 (0.338)	0.240	339.4 (319.6)
	600	-0.044 (0.330)	0.256	334.1 (337.4)
	500	-0.049 (0.351)	0.292	284.5 (302.5)
	400	-0.043 (0.326)	0.248	277.8 (319.8)
	300	-0.043 (0.329)	0.332	260.7 (283.3)
	200	-0.039 (0.309)	0.340	224.6 (250.3)
	100	-0.044 (0.317)	0.516	124.4 (149.2)
	50	-0.037 (0.282)	0.592	85.1 (107.0)
	25	-0.048 (0.293)	0.840	49.5 (56.1)
San Miguel	15	-0.035 (0.329)	0.868	68.0 (65.9)
	20	-0.043 (0.324)	0.836	86.3 (121.2)
	40	-0.041 (0.336)	0.720	127.1 (131.4)
	60	-0.038 (0.351)	0.588	110.2 (128.5)
	80	-0.045 (0.383)	0.552	134.7 (153.2)
	100	-0.042 (0.355)	0.468	113.1 (130.3)
	200	-0.036 (0.353)	0.372	168.6 (162.2)
	300	-0.045 (0.371)	0.352	170.6 (170.1)
	400	-0.041 (0.361)	0.304	170.0 (156.5)
Santa Cruz	80	-0.045 (0.343)	0.548	118.1 (156.2)
	100	-0.042 (0.351)	0.508	193.5 (275.3)
	200	-0.039 (0.345)	0.356	253.6 (307.1)
	300	-0.037 (0.340)	0.284	312.3 (352.0)
	400	-0.034 (0.330)	0.236	354.0 (365.7)
	500	-0.034 (0.340)	0.212	393.6 (407.0)
	600	-0.039 (0.348)	0.236	405.1 (407.1)
	800	-0.042 (0.359)	0.200	325.8 (356.3)
	1000	-0.040 (0.352)	0.176	389.9 (403.4)

Figure 3. Extinction risk profiles for selected Channel Island fox populations. Influence of initial population size on extinction risk over 50 years in the absence of a disease catastrophe (black bars), or in the presence of a mild or severe canine distemper epidemic (see text for details of disease parameterization). Current or very recent estimated wild population size for each island is indicated by the asterisk.



IV. Risk Assessment II: Population Supplementation Analysis

The preceding section has demonstrated the measurable extinction risks faced by small populations of Channel Island foxes. Moreover, this risk is likely to increase dramatically if the type of distemper event recently seen on Santa Catalina is allowed to occur in the future. With this information in hand, it is imperative that management strategies are developed to minimize this risk. An important component of a larger strategy could involve supplementation of the wild population with captive-born individuals. This alternative was evaluated using Vortex in order to provide some insight into the optimal means by which a supplementation program could be implemented.

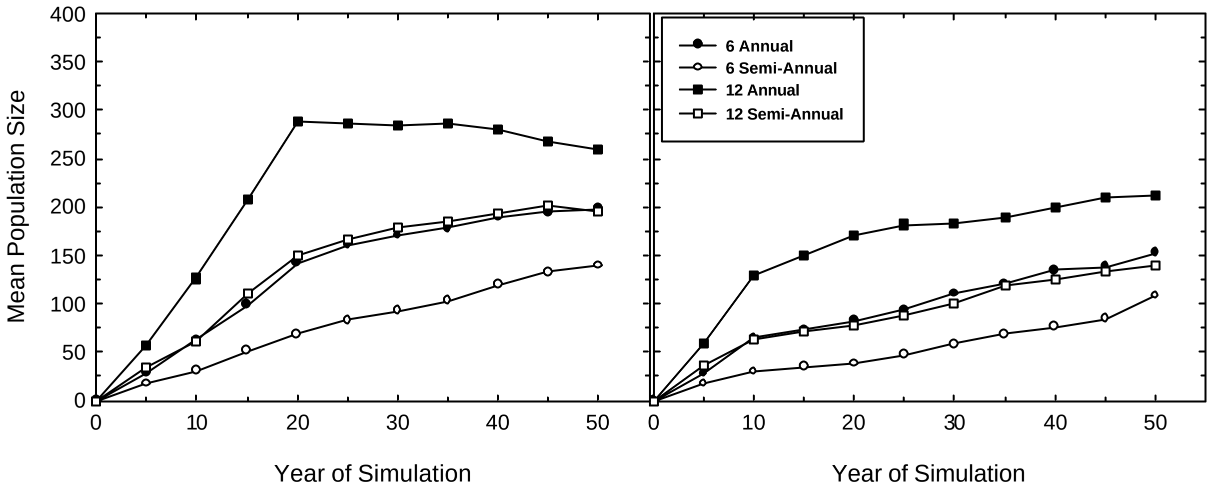
A total of eight different supplementation scenarios were devised. Common to each scenario was the supplementation of equal numbers of 1 year-old male and female foxes.

Scenario A – 6 individuals added to a population annually for 20 years
Scenario B – 6 individuals added to a population every other year for 20 years
Scenario C – 12 individuals added to a population annually for 20 years
Scenario D – 12 individuals added to a population every other year for 20 years
Scenario E – 6 individuals added to a population annually for 10 years
Scenario F – 6 individuals added to a population every other year for 10 years
Scenario G – 12 individuals added to a population annually for 10 years
Scenario H – 12 individuals added to a population every other year for 10 years

These scenarios were evaluated for San Miguel and Santa Cruz Island populations (San Clemente was not chosen because of the considerably larger size of that population under current conditions). Disease was included as a catastrophe in a manner identical to those models discussed in the previous section. Finally, an attempt was made to model current conditions as accurately as possible with respect to current wild population sizes. For San Miguel, we assumed that the wild population was effectively gone (i.e., initial population size = 0), while the Santa Cruz population was estimated to consist of 80 individuals. The Santa Cruz scenarios were repeated with initial population sizes of 40 and 20 individuals in order to evaluate the success of a supplementation program as a function of wild population size. In this context, success of a program is defined in terms of reduced risk of wild population extinction.

A representative set of population trajectories for supplemented populations on San Miguel can be seen in Figure 4. The increased population growth rate over the first 10 – 20 years, when supplementation is actually occurring, can be clearly seen in the individual plots. These simulations demonstrate that the greatest rate of population growth can be achieved (not surprisingly) by supplementing the wild population with the maximum number of foxes annually. On the other end of the spectrum, supplementing just six individuals every other year leads to comparatively poor population performance. As might be expected, supplementing six individuals every year leads to a population response that is very similar to a scenario in which twelve individuals are supplemented every other year.

Figure 4. Population trajectories for a simulated San Miguel fox population initiated with captive-born animals and subsequently supplemented with 6 or 12 individuals (equal sex ratio), annually or semi-annually, for a period of twenty years (left panel) or ten years (right panel).



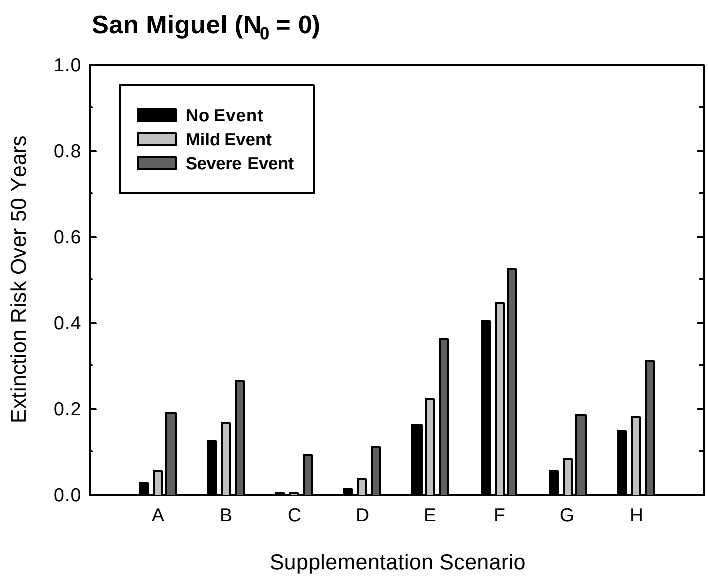


Figure 5. Extinction risk profiles among alternative supplementation scenarios for a simulated San Miguel fox population in the presence of a distemper-like disease catastrophe. Supplementation scenarios include:

Scenario A – 6 individuals added annually for 20 years
Scenario B – 6 individuals added every other year for 20 years
Scenario C – 12 individuals added annually for 20 years
Scenario D – 12 individuals added every other year for 20 years
Scenario E – 6 individuals added annually for 10 years
Scenario F – 6 individuals added every other year for 10 years
Scenario G – 12 individuals added annually for 10 years
Scenario H – 12 individuals added every other year for 10 years

Given these representative population trajectories, what do the extinction risk profiles look like for these supplementation profiles on San Miguel and Santa Cruz Islands? The results of this analysis can be found in Figures 5 and 6 and Tables 5 – 8. Overall, extinction risk is reduced if

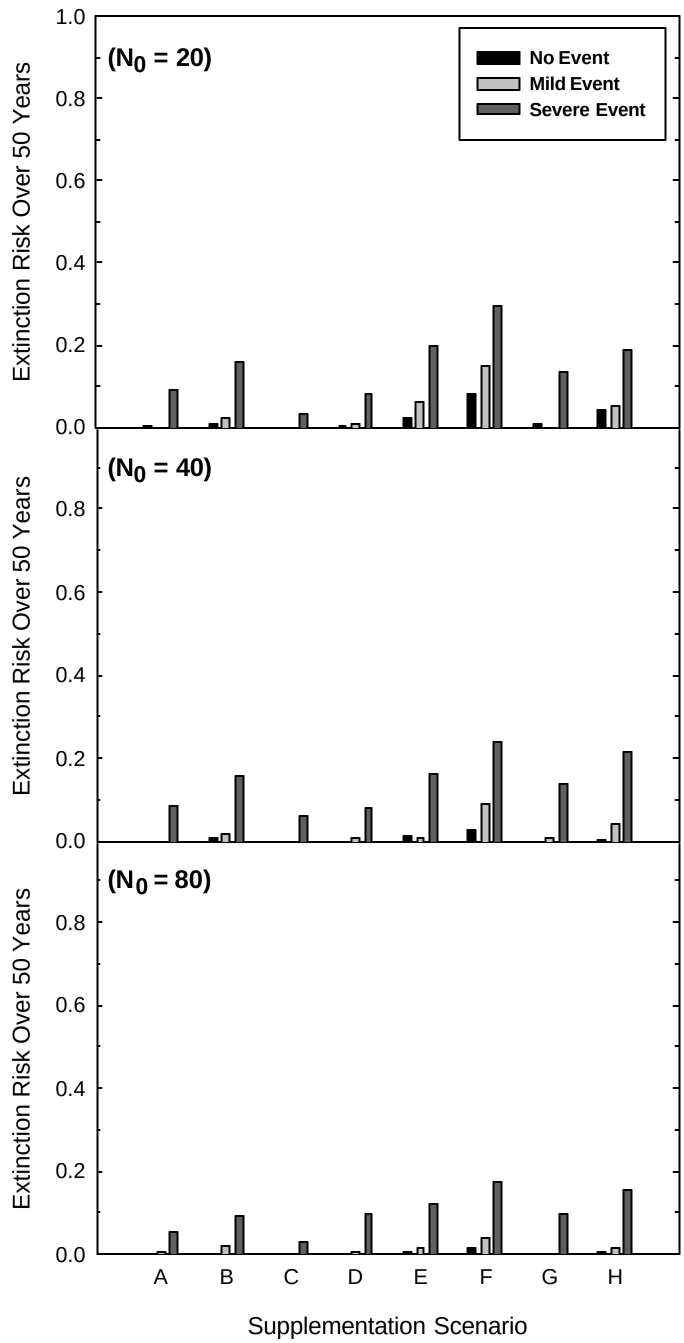


Figure 6. Extinction risk profiles among alternative supplementation scenarios for a simulated Santa Cruz fox population in the presence of a distemper-like disease catastrophe. Details of supplementation scenarios are described in Figure 5.

supplementation continues for a 20-year period as compared to a 10-year period. However, adding just 6 individuals every year for 20 years in the absence of disease leads to a risk of population extinction of greater than 12% – possibly unacceptably high under most circumstances. This relatively high risk of extinction no doubt arises from the fact that the wild population is absent at year 0, leading to very small initial population sizes and significant impacts from demographic and environmental stochasticity. When disease is included, the extinction risks increase and the overall situation becomes less satisfactory.

The results for simulated Santa Cruz populations show that delaying the initiation of a supplementation program until wild population sizes are reduced can lead to a less effective program. As the initial population size decreases from 80 to 20, extinction risks increase within individual supplementation scenarios, particularly in the face of disease. However, most of the risks faced by these populations remain less than 10% over the 50-year timeframe of the simulations. Not surprisingly, these results in combination with the San Miguel lend substantial support to the notion that supplementation and reintroduction efforts can be much more effective when recipient wild populations are large enough to be buffered from many of the detrimental consequences of stochastic variation in vital rates.

Summary and Conclusions

- Using stochastic population simulation techniques, models were developed that predicted within reason a set of recent declines among Channel Island fox populations on San Clemente, San Miguel, and Santa Cruz Islands. The predictive nature of these models lent credibility to the subsequent population viability analyses that addressed issues of stochastic extinction risk and supplementation program efficacy.
- A form of sensitivity analysis was employed to define a “mortality space” within which age-specific mortality rates would lead to positive population growth. This type of analysis provides insight into the degree of management that may be needed to reduce mortality from current and unsustainable levels to those that would foster population growth.
- Even if those factors contributing to additional fox mortality are largely controlled, many of the remnant small populations are at risk of extinction within the next 50 years. This risk of extinction is greatly enhanced if infrequent but severe disease epidemics, similar to the recent canine distemper epidemic found on Santa Catalina, are explicitly considered. These simulations, parameterized according to recent field data, suggest that disease epidemics could be a significant threat to remnant fox populations and could become the final agent that causes island-wide extinction. Considerable attention must be directed toward the vigorous management of invasive canines (e.g., domestic dogs) that occasionally visit the islands.
- Given the significant extinction risk faced by remnant fox populations, the efficacy of alternative supplementation programs using captive stock was evaluated. Overall, augmenting wild populations with between 6 and 12 animals annually for as little as 10 years can significantly reduce the long-term risk of population extinction. However, these results are highly dependent on the additional risk posed by epidemic disease and the size of the recipient wild population.

Table 5. Impact of proposed supplementation scenarios on viability of simulated fox populations occupying San Miguel Island. In each scenario, the wild population is initially absent ($N_0 = 0$), pup mortality is taken to be 45% and non-pup mortality is chosen from the value listed in Table 1 that gives a mean growth rate of approximately 0.0. Output listed includes the stochastic growth rate (with standard deviation), the probability of population extinction within a 50-year time period, and mean (standard deviation) size of populations remaining extant over 50 years.

Supplementation Scenario*	r_s (SD)	P(E)	N_{50} (SD)
No disease event			
A	0.064 (0.220)	0.028	197.6 (148.9)
B	0.048 (0.263)	0.124	139.3 (134.2)
C	0.065 (0.211)	0.004	258.4 (151.2)
D	0.051 (0.247)	0.012	194.6 (136.8)
E	0.047 (0.233)	0.160	152.4 (153.3)
F	0.029 (0.283)	0.404	108.7 (126.2)
G	0.052 (0.221)	0.056	212.5 (156.5)
H	0.033 (0.258)	0.148	139.9 (137.2)
Mild disease event			
A	0.058 (0.232)	0.052	177.4 (148.7)
B	0.040 (0.278)	0.164	106.7 (115.6)
C	0.062 (0.221)	0.004	248.1 (156.0)
D	0.046 (0.258)	0.036	171.3 (139.1)
E	0.038 (0.250)	0.220	119.0 (132.5)
F	0.027 (0.293)	0.444	101.9 (112.4)
G	0.041 (0.235)	0.080	167.3 (154.4)
H	0.028 (0.270)	0.180	130.4 (144.0)
Mild disease event			
A	0.052 (0.297)	0.188	182.1 (154.6)
B	0.034 (0.331)	0.264	97.6 (116.3)
C	0.050 (0.303)	0.092	213.7 (164.1)
D	0.041 (0.308)	0.108	192.6 (166.1)
E	0.031 (0.322)	0.360	91.9 (105.3)
F	0.022 (0.329)	0.524	81.3 (99.7)
G	0.034 (0.308)	0.184	157.3 (139.7)
H	0.023 (0.327)	0.312	124.0 (122.0)

Scenario definitions:
Scenario A – 6 individuals added to a population annually for 20 years
Scenario B – 6 individuals added to a population every other year for 20 years
Scenario C – 12 individuals added to a population annually for 20 years
Scenario D – 12 individuals added to a population every other year for 20 years
Scenario E – 6 individuals added to a population annually for 10 years
Scenario F – 6 individuals added to a population every other year for 10 years
Scenario G – 12 individuals added to a population annually for 10 years
Scenario H – 12 individuals added to a population every other year for 10 years

Table 6. Impact of proposed supplementation scenarios on viability of simulated fox populations occupying Santa Cruz Island. In each scenario, the wild population is estimated to be 20 animals (N_0 = 20), pup mortality is taken to be 45% and non-pup mortality is chosen from the value listed in Table 1 that gives a mean growth rate of approximately 0.0. Output listed includes the stochastic growth rate (with standard deviation), the probability of population extinction within a 50-year time period, and mean (standard deviation) size of populations remaining extant over 50 years.

Supplementation Scenario*	r_s (SD)	P(E)	N_{50} (SD)
No disease event			
A	0.057 (0.154)	0.004	468.1 (342.6)
B	0.043 (0.164)	0.008	269.4 (255.7)
C	0.070 (0.163)	0.000	656.2 (370.3)
D	0.054 (0.171)	0.004	414.9 (321.5)
E	0.044 (0.160)	0.024	319.3 (315.7)
F	0.029 (0.172)	0.084	199.2 (233.0)
G	0.055 (0.168)	0.008	447.1 (361.0)
H	0.043 (0.175)	0.044	327.7 (314.2)
Mild disease event			
A	0.050 (0.170)	0.000	349.6 (300.1)
B	0.037 (0.177)	0.024	228.6 (235.6)
C	0.064 (0.177)	0.000	572.7 (364.2)
D	0.047 (0.188)	0.008	361.0 (341.7)
E	0.035 (0.181)	0.060	264.0 (290.4)
F	0.020 (0.186)	0.148	165.2 (209.9)
G	0.038 (0.267)	0.136	362.2 (348.2)
H	0.035 (0.194)	0.052	261.9 (279.1)
Severe disease event			
A	0.039 (0.261)	0.092	353.4 (352.6)
B	0.026 (0.270)	0.160	220.0 (259.0)
C	0.053 (0.266)	0.032	493.5 (401.1)
D	0.043 (0.278)	0.080	357.5 (331.9)
E	0.024 (0.266)	0.196	225.7 (261.8)
F	0.010 (0.286)	0.296	167.6 (227.5)
G	0.038 (0.267)	0.136	362.2 (348.2)
H	0.027 (0.270)	0.188	246.5 (282.7)

See Table 5 for a description of each supplementation scenario

Table 7. Impact of proposed supplementation scenarios on viability of simulated fox populations occupying Santa Cruz Island. In each scenario, the wild population is estimated to be 40 animals (N_0 = 40), pup mortality is taken to be 45% and non-pup mortality is chosen from the value listed in Table 1 that gives a mean growth rate of approximately 0.0. Output listed includes the stochastic growth rate (with standard deviation), the probability of population extinction within a 50-year time period, and mean (standard deviation) size of populations remaining extant over 50 years.

Supplementation Scenario	r_s (SD)	P(E)	N_{50} (SD)
No disease event			
A	0.042 (0.146)	0.000	439.2 (329.8)
B	0.032 (0.155)	0.008	338.1 (323.9)
C	0.055 (0.150)	0.000	649.9 (363.6)
D	0.045 (0.155)	0.000	500.1 (355.4)
E	0.037 (0.152)	0.012	407.1 (357.0)
F	0.023 (0.160)	0.028	260.2 (283.5)
G	0.045 (0.152)	0.000	503.4 (346.3)
H	0.037 (0.160)	0.004	390.9 (333.4)
Mild disease event			
A	0.040 (0.162)	0.000	423.7 (330.3)
B	0.027 (0.172)	0.020	261.5 (272.6)
C	0.050 (0.166)	0.000	555.2 (348.0)
D	0.039 (0.173)	0.008	423.4 (356.0)
E	0.028 (0.169)	0.008	299.9 (324.1)
F	0.018 (0.174)	0.088	240.9 (274.4)
G	0.040 (0.169)	0.008	436.4 (360.7)
H	0.027 (0.174)	0.040	310.1 (307.9)
Severe disease event			
A	0.028 (0.258)	0.084	377.5 (335.0)
B	0.012 (0.286)	0.156	241.2 (293.0)
C	0.034 (0.275)	0.060	451.2 (390.1)
D	0.028 (0.264)	0.080	352.6 (324.1)
E	0.017 (0.262)	0.164	300.8 (327.3)
F	0.006 (0.264)	0.240	211.9 (245.0)
G	0.026 (0.270)	0.140	405.5 (377.9)
H	0.014 (0.285)	0.216	302.4 (318.5)

See Table 5 for a description of each supplementation scenario

Table 8. Impact of proposed supplementation scenarios on viability of simulated fox populations occupying Santa Cruz Island. In each scenario, the wild population is taken to be 80 animals (N_0 = 80), pup mortality is taken to be 45% and non-pup mortality is chosen from the value listed in Table 1 that gives a mean growth rate of approximately 0.0. Output listed includes the stochastic growth rate (with standard deviation), the probability of population extinction within a 50-year time period, and mean (standard deviation) size of populations remaining extant over 50 years.

Supplementation Scenario	r_s (SD)	P(E)	N_{50} (SD)
No disease event			
A	0.035 (0.143)	0.000	540.8 (351.5)
B	0.029 (0.146)	0.000	477.8 (380.9)
C	0.044 (0.143)	0.000	700.1 (351.7)
D	0.036 (0.145)	0.000	575.0 (369.2)
E	0.029 (0.145)	0.004	452.0 (319.6)
F	0.020 (0.150)	0.016	353.7 (324.7)
G	0.036 (0.145)	0.000	550.8 (357.8)
H	0.028 (0.149)	0.004	454.9 (349.9)
Mild disease event			
A	0.032 (0.158)	0.004	517.7 (367.5)
B	0.020 (0.165)	0.020	378.9 (338.3)
C	0.041 (0.158)	0.000	640.2 (381.7)
D	0.031 (0.162)	0.004	494.0 (347.6)
E	0.018 (0.163)	0.016	324.5 (297.7)
F	0.013 (0.165)	0.040	320.2 (322.3)
G	0.031 (0.159)	0.000	488.0 (375.2)
H	0.022 (0.165)	0.016	406.8 (358.4)
Severe disease event			
A	0.018 (0.253)	0.056	403.1 (355.3)
B	0.009 (0.278)	0.092	348.0 (349.6)
C	0.026 (0.266)	0.028	509.7 (417.0)
D	0.015 (0.278)	0.096	384.1 (356.3)
E	0.007 (0.254)	0.120	324.6 (325.9)
F	0.000 (0.276)	0.176	274.8 (312.0)
G	0.015 (0.260)	0.096	425.4 (370.6)
H	0.005 (0.274)	0.156	340.1 (355.0)

See Table 5 for a description of each supplementation scenario

Sample *VORTEX* Input File

```
SMIS009.OUT     ***Output Filename***
Y      ***Graphing Files?***
N      ***Details each Iteration?***
250     ***Simulations***
50     ***Years***
5      ***Reporting Interval***
0      ***Definition of Extinction***
1      ***Populations***
N      ***Inbreeding Depression?***
Y      ***EV concordance between repro and surv?***
1      ***Types Of Catastrophes***
M      ***Monogamous, Polygynous, or Hermaphroditic***
1      ***Female Breeding Age***
1      ***Male Breeding Age***
9      ***Maximum Breeding Age***
50.000000     ***Sex Ratio (percent males)***
4      ***Maximum Litter Size (0 = normal distribution) *****
N      ***Density Dependent Breeding?***
SanMiguel
(18.9*(A=1))+(60.0*(A>=2))  **breeding
17.00  **EV-breeding
32.400000     ***SanMiguel: Percent Litter Size 1***
41.200000     ***SanMiguel: Percent Litter Size 2***
14.700000     ***SanMiguel: Percent Litter Size 3***
45.000000  *FMort age 0
8.000000  ***EV
24.000000  *Adult FMort
6.000000  ***EV
45.000000  *MMort age 0
8.000000  ***EV
24.000000  *Adult MMort
6.000000  ***EV
1.000000     ***Probability Of Catastrophe 1***
1.000000  ***Severity--Reproduction***
0.100000  ***Severity--Survival***
Y      ***All Males Breeders?***
Y      ***Start At Stable Age Distribution?***
0      ***Initial Population Size***
500     ***K***
0.000000     ***EV--K***
N      ***Trend In K?***
N       ***Harvest?***
Y      ***Supplement?***
1      ***First Year Supplementation***
20      ***Last Year Supplementation***
2      ***Supplementation Interval***
3      ***Females Age 1 Supplemented***
3      ***Males Age 1 Supplemented***
Y      ***AnotherSimulation?***
```